UNIVERSITY OF CALIFORNIA PUBLICATIONS
IN
BOTANY
Vol. 7, Nos. 6-7-8, pp. 159-278, pls. 18-20, 8 figs. in text. November 7, 1919

A RUBBER PLANT SURVEY OF WESTERN NORTH AMERICA

BY
HARVEY MONROE HALL
AND
THOMAS HARPER GOODSPEED

UNIVERSITY OF CALIFORNIA PRESS
BERKELEY

UNIVERSITY OF CALIFORNIA PUBLICATIONS

Note.—The University of California Publications are offered in exchange for the publications of learned societies and institutions, universities and libraries. Complete lists of all the publications of the University will be sent upon request. For sample copies, lists of publications and other information, address the MANAGER OF THE UNIVERSITY PRESS, BERKELEY, CALIFORNIA, U. S. A. All matter sent in exchange should be addressed to THE EXCHANGE DEPARTMENT, UNIVERSITY LIBRARY, BERKELEY, CALIFORNIA, U. S. A.

WILLIAM WESLEY & SONS, LONDON

Agent for the series in American Archaeology and Ethnology, Botany, Geology, Physiology, and Zoology.

BOTANY.—W. A. Setchell, Editor. Price per volume, $3.50; beginning with vol. 5, $5.00. Volumes I (pp. 418), II (pp. 360), III (pp. 400), IV (pp. 379), completed. Volumes V, VI and VII in progress.

Cited as Univ. Calif. Publ. Bot.

A RUBBER PLANT SURVEY

OF

WESTERN NORTH AMERICA

I. CHRYSOTHAMNUS NAUSEOSUS AND ITS VARIETIES

HARVEY MONROE HALL

II. CHRYSIL, A NEW RUBBER FROM CHRYSOTHAMNUS NAUSEOSUS

HARVEY MONROE HALL AND THOMAS HARPER GOODSPEED

III. THE OCCURRENCE OF RUBBER IN CERTAIN WEST AMERICAN SHRUBS

HARVEY MONROE HALL AND THOMAS HARPER GOODSPEED

UNIVERSITY OF CALIFORNIA PUBLICATIONS
IN
BOTANY

Vol. 7, No. 6, pp. 159-181 November 7, 1919

I. *CHRYSOTHAMNUS NAUSEOSUS* AND ITS VARIETIES

BY

HARVEY MONROE HALL

CONTENTS

I. INTRODUCTION AND ACKNOWLEDGMENTS

In the course of an investigation of *Chrysothamnus* as a possible source of rubber, it has been found necessary to give considerable attention to the botanical relationships of the species and varieties of this genus of shrubs. Even before that investigation was begun in 1917, the author had undertaken a revision of the group and although the preparation of this has been delayed by the rubber studies it is intended now to carry it forward to completion. In the meantime, however, it is necessary that the forms discussed in the rubber report be properly defined and that those not hitherto recognized be named and described. These are the reasons for the publication of this preliminary paper.

Chrysothamnus is a genus of the Aster Tribe of the Compositae and belongs to what is often called the Haplopappus group. From related genera it differs chiefly in the more cylindraceous involucre, the bracts of which are usually more or less keeled and tend to fall into five vertical ranks. Although these characters are too variable to give to the genus that sharpness of delimitation that one would like, yet there can be no question as to its homogeneity. It represents what

is perhaps the most satisfactory result of all of the numerous attempts to set up genera in this group where generic limits are admittedly most difficult to establish.

Within the genus we find a multitude of natural forms of greater or less significance. This has led botanists greatly to increase the number of species and varieties, so that not less than one hundred and thirteen of these have been described and this number could be multiplied several times through more extensive field studies and without the employment of characters other than those already proposed for the basis of species. This is partly because these single characters have been variously united in nature to form a large number of combinations, but it is also because of the extreme variability of some of the characters themselves. The numerous forms of *Chrysothamnus* may be assembled into five natural groups as follows:

KEY TO THE SECTIONS OF *CHRYSOTHAMNUS*

Herbage not resinous-punctate: leaves oblanceolate to narrowly linear or terete.
  Heads in leafy spike-like or raceme-like clusters: outer bracts of the involucre prolonged into a slender herbaceous tip or appendage .... Section 1. PARRYANI
    (Principal species: *Parryi, Howardi.*)
  Heads cymose, paniculate, or solitary at the ends of the branches: bracts obtuse to acuminate, devoid of herbaceous tip.
    Twigs not tomentose, either smooth and glabrous or only scabrid or puberulent: style-appendages from included to long-exserted.
      Bracts strongly keeled, in five very distinct vertical ridges .... Section 2. PULCHELLI
        (Principal species: *pulchellus, depressus.*)
      Bracts scarcely keeled and the vertical ridges obscure..Section 3. TYPICI
        (Principal species: *albidus, Greenei, gramineus, Vaseyi, viscidiflorus.*)
    Twigs closely covered with a pannose tomentum which usually persists for several years: style-appendages mostly longer than the stigmatic portion and long-exserted .... Section 4. NAUSEOSI
      (Single species: *nauseosus.*[1])
Herbage resinous-punctate: leaves terete .... Section 5. PUNCTATI
  (Principal species: *teretifolius, paniculatus.*)

Of the above five groups rubber has been found in more than minute quantities only in the *Nauseosi* and *Punctati*. Since the latter

[1] It is possible that *C. formosus* Greene and *C. turbinatus* (M. E. Jones) Rydb. constitute additional species of this group. See p. 180.

of these groups comprises only two species, and since these two species are already well defined in the literature and are not inclined to break up into numerous variants in nature, it is at the present time necessary to consider only the *nauseosus* group.

Taking *Chrysothamnus nauseosus* as comprising all of the forms of the *Nauseosi,* as indicated in the above key, we find its best distinguishing character to be the presence of a most remarkable pannose tomentum on the young twigs. It is fully recognized that pubescence characters often furnish but a very treacherous basis for constant species, yet in this instance the nature of the pubescence is so unlike that in any other species of the genus, and it is so obviously correlated with habit and other minor characters that it seems certainly to indicate a natural group. This felt-like covering to the twigs is more or less infiltrated with a resinous substance. In some forms the surface is loose and fluffy, the tomentum thus more or less completely masking the striae of the stems. In these forms the surface is usually light gray or dull white or even almost pure white, and the loose tomentum extends even to the involucres. The original *C. nauseosus* is one of these forms. In other varieties the surface of the tomentum is firm and smooth, thus revealing the striae. In these forms the twigs are dull to bright yellowish green in color or rarely somewhat whitish and the involucres are mostly glabrous.

Within what is here included under *C. nauseosus,* previous writers have described forty forms, all but six of which have been accorded specific rank at one time or another. In the present paper two new varieties are added. Nothing can be more certain than that these forty-two attempts to recognize species and varieties do not by any means exhaust the resources of the group. Every autumnal excursion into a new district brings to light one or more forms not previously described. The only limits set to the number of new species or varieties which might be set up lie in one's ability to visit all parts of the field during the flowering period and the failure or disinclination to recognize minute variations. Yet the systematist should include in his ultimate object not only the recognition of this multitude of forms but also their proper arrangement in a scheme which will display their natural relationships. Since this would entail an enormous amount of detailed labor, including extensive experiments, and since the results, even if attainable, would be of but little practical value at the present time, the writer has satisfied himself with the acceptance of twenty-two forms, all of which are treated as varieties.

This is believed to provide for all of the principal forms, and it is quite certain that each of the described varieties is a natural unit, although in most cases it is itself made up of still smaller variants.

Although the relationships between the varieties accepted in this paper are expressed somewhat in the arrangement, and in the form of brief notes from time to time, yet our actual knowledge of these matters is so slight that it seems unwise to attempt an expression of it through an elaborate system of polynomials. Some of the varieties are based upon characters which are at least partially heritable, while others are doubtless ecologic forms. In some cases two varieties occupying the same territory may be easily distinguished by a number of characters which at that locality do not overlap in their variations; yet as forms from other places are brought into comparison, it is discovered that these characters are so variable that they cannot be used for the recognition of species in the broad sense. It seems almost certain that after all of the forms shall have been assembled it will be found that no two of the characters thus far proposed for the separation of "species" in this group will be found to vary in unison, and furthermore that there is not a single one of them that does not vary by imperceptible degrees. Therefore we need not be surprised ultimately to find as many forms as there are possible combinations of characters and to have, in addition, numerous forms which cannot be satisfactorily placed because of the intermediate nature of one or more of the characters. It is thus seen to be impossible to accord specific rank to any of the units of this exceedingly complex and variable assemblage of forms unless one is willing to accept a species concept so narrow that its usefulness would be lost because of the impossibility of definite application.

If some readers object to the use of even trinomials we would suggest that the binomial indicating the inclusive major species, that is, *Chrysothamnus nauseosus* in this case, is all that need be used in most instances, while in any special paper on the group the varietal name alone may be used without confusion, since the generic and specific names are understood. This practice will be followed in the report on *Chrysothamnus* as a possible source of rubber, in which paper the actual working out of the method may be observed.

In preparing the following synopsis, the presence or absence of hairs on the involucre is taken as the principal character, notwithstanding its variable nature. This is done because it comes the nearest to assembling the forms into what seem to be natural groups, or sub-

species. Every other character tried, such as size or shape of the leaves or of the parts of the involucre or flower, the nature of the pappus or style-branches, and the pubescence of the akenes, have all been found to be even more variable and not to serve well as a basis for a natural classification. Moreover, the pubescent involucre is nearly always associated with a white or grayish appearance of the foliage so that the use of this character divides the whole species into two series of varieties, which series may, for the most part, be recognized by their general appearance.

After the foregoing remarks as to the variability of characters in this species it will perhaps be understood that one cannot expect to use the key to varieties with entire satisfaction. The large number of intermediate forms and the numerous permutations of characters render it impossible to prepare a key whereby one may definitely identify every specimen that comes to hand. It is believed, however, that with the exception of one or two little-known forms of eastern Oregon and Washington, all of the major variants have been accounted for.

This study has been greatly facilitated through the assistance of a considerable number of people but since these will be specifically mentioned in the report on the rubber plant investigations the list need not be given here. Acknowledgment should be made at this place, however, of the kindness of Dr. B. L. Robinson, of the Gray Herbarium of Harvard University, and also of that of Dr. P. A. Rydberg, of the New York Botanical Garden, in permitting the author to examine certain type specimens in their charge. Furthermore, Dr. Aven Nelson has made available the rich collections of the Rocky Mountain Herbarium at the University of Wyoming.

II. KEY TO THE VARIETIES OF *CHRYSOTHAMNUS NAUSEOSUS*[2]

Series A. The Gray Forms

Involucres tomentulose (at least the short outer bracts) to densely woolly: foliage mostly gray or even white with a rather copious pubescence, this either fine and close or floccose-tomentose (least pronounced in *oreophilus* and *speciosus*).

Akenes densely strigose.

Tomentum loose, copious, and nearly pure white on twigs and leaves, extending to the involucres: corolla-tube nearly always arachnoid-pubescent.

[2] See also doubtful forms on p. 180.

Inner bracts of involucre plainly tomentose or if nearly glabrous the bracts then acute.

Corolla-lobes lanceolate, 1 to 2 mm. long: involucral bracts acute (at least in part) ....1. *nauseosus* s. str.

Corolla-lobes short-ovate, less than 1 mm. long: bracts all very obtuse. 2. *hololeucus*

Inner bracts smooth and glabrous or nearly so, very obtuse ....3. *latisquameus*

Tomentum close, compact, smooth, and usually grayish on twigs and leaves: corolla-tube glabrous or puberulent, not arachnoid-pubescent.

Leaves 3 to 6 mm. wide: bracts very obtuse ....4. *salicifolius*

Leaves less than 3 mm. wide: bracts various but mostly acute.

Bracts abruptly acute. Far western ....6. *occidentalis*

Bracts gradually acute or somewhat obtuse.

Involucre 7 to 9 or rarely 10 mm. high.

Shrubs normally 5 to 20 dm. high: corolla 8 to 10 mm. long or rarely only 7 mm. in *gnaphalodes* (*latisquameus* of Arizona and New Mexico, with broad and very obtuse and smooth inner bracts might be sought here).

Leaves of flowering twigs 1 to 3 cm. long, not numerous: herbage usually fragrant ....5. *gnaphalodes*

Leaves of flowering twigs mostly over 3 cm. long, often crowded: herbage not fragrant ....7. *speciosus*

Shrubs only 2 to 6 dm. high: corolla 6 to 8 mm. long (very rarely 9 mm.).

Leaves erect or ascending: bracts all tomentulose or ciliate..8. *frigidus*

Leaves spreading or recurved: only the outer bracts tomentulose. 9. *plattensis*

Involucre 11 to 12 mm. or rarely only 10 mm. high ....10. *bernardinus*

Akenes glabrous.

Bracts of the involucre acuminate ....11. *Bigelovii*

Bracts of the involucre obtuse ....12. *glareosus*

Series B. The Green Forms

Involucres perfectly glabrous although sometimes viscidulous or glandular: foliage mostly greenish, the tomentum rather sparse or wanting on mature leaves.

Akenes glabrous ....13. *leiospermus*

Akenes densely strigose.

Leaves linear, mostly more than 1 mm. wide,[3] mostly 3 to 5-nerved except in *bernardinus*.

Involucre 6 to 8 mm. long: corolla 6 to 9 mm. long; lobes 1 mm. or less long ....14. *graveolens*

Involucre 9 mm. or more long: corolla 9 to 10 mm. long; lobes 1 mm. or more long. Western forms.

Heads 8 to 10-flowered: leaves flat or twisted, 2 to 5 mm. wide. 15. *californicus*

Heads 5-flowered (rarely 6-flowered): leaves often conduplicate, 1 to 2 mm. wide ....10. *bernardinus*

Leaves linear-filiform or very narrowly linear, mostly 1 mm. or less wide (except in *occidentalis*), 1-nerved.

[3] Care must be exercised in making this measurement since the leaves are often longitudinally folded. The figures given are for the total width of the flat leaf.

Bracts of the involucre abruptly pointed or some only acute. Far western.
Tip of the bract short, erect ....6. *occidentalis*
Tip of the bract about 1 mm. long, very slender, recurved....16. *ceruminosus*
Bracts obtuse to acute, not abruptly pointed.
Corolla-lobes glabrous.
Involucre 6 to 9 mm. long, not sharply angled.
Bracts ciliate, the outer often slightly hairy also on back, flat, thin, scarcely keeled ....17. *oreophilus*
Bracts not ciliate, all perfectly glabrous, concave, somewhat keeled.
Corolla 7 to 8.3 mm. long; lobes under 2 mm.: twigs and foliage slender.
Lobes of corolla 0.5 to 1 mm. long, rarely more: inflorescence typically rounded to pyramidal. Rocky Mountain states.
18. *pinifolius*
Lobes of corolla 1 to 2 mm. long: inflorescence typically cylindric to pyramidal. Great Basin ....19. *consimilis*
Corolla 8 to 10 mm. long; lobes 1.7 to 2.5 mm. long: twigs and foliage stouter. Southwestern ....20. *viridulus*
Involucre 9 to 10 mm. long, sharply 5-angled, the strongly keeled bracts in very distinct vertical rows ....21. *mohavensis*
Corolla-lobes sparsely long-hairy in the bud: shrub nearly leafless.
22. *junceus*

III. SYNOPSIS OF THE VARIETIES OF *CHRYSOTHAMNUS NAUSEOSUS*

1. **Chrysothamnus nauseosus** (Pall.) Britt. (*sensu strictu*) *in* Britt and Br., Ill. Fl., vol. 3, p. 326, 1898.

Chrysocoma nauseosa Pall., *in* Pursh, Fl., vol. 2, p. 517, 1814.
Chrysothamnus speciosus albicaulis Nutt., Trans. Am. Philos. Soc., ser. 2, vol. 7, p. 324, 1841.
Bigelovia graveolens albicaulis Gray, Proc. Am. Acad., vol. 8, p. 645, 1873.

Shrub 5 to 10 dm. high, with numerous erect or ascending twigs, leafy to the top, permanently white-tomentose throughout; twigs not evidently striate: leaves narrowly linear, 3 to 6 cm. long, 0.5 to 1.5 mm. wide: inflorescence a rather loose round-topped cyme: involucre 7 to 8 mm. high; bracts mostly acute, plainly keeled, in 5 distinct vertical ranks, white-woolly but not ciliate: corolla 7.5 to 9 mm. long; tube perhaps always cobwebby with long weak hairs; lobes lanceolate, 1 to 2 mm. long.

This type form of the species is much less common than many of its varieties. It occurs from Utah to Oregon and probably north to British Columbia and Montana, inhabiting well drained soil with little or no alkali. In the typical form, as understood by the writer, the leaves are very narrow and, like the twigs, are entirely covered with a white flocculent tomentum, while the corolla-tube is conspicu-

ously arachnoid-pubescent. Such are specimens gathered by Leiberg in eastern Washington under no. 884 and others by Marcus E. Jones at Marysvale, Utah, under no. 5968. In northern Mono County, California, is encountered a form in which the leaves are 2 to 3 mm. wide and the inflorescence is more compact and rounded (H. M. H., no. 463), but in the pubescence of the corolla-tube and in all other characters than those mentioned it is plainly *nauseosus.* Nearly identical are specimens from Truckee, California (Heller, no. 7192). Another divergence is indicated by specimens with the broad leaves and other characters of the Mono and Truckee collections just cited but with a corolla-tube which is only crisp-pubescent as in most varieties. A recognition of these forms would lead only to confusion since further field studies would doubtless reveal still other divisions that might be made. They are therefore retained in this paper as only trivial variants of *nauseosus.* *C. orthophyllus* Greene, Pitt., vol. 5, p. 62, 1902, known only from Plumas County, California, is described as less than a foot high and with the tips of the corolla-lobes as well as the tube long-villous.

2. **Chrysothamnus nauseosus** var. **hololeucus** (Gray) comb. nov.

Bigelovia graveolens var. *hololeuca* Gray, Proc. Am. Acad., vol. 8, p. 645, 1873.

Shrub 6 to 18 dm. high and fully as broad, closely branched and usually of rounded outline, leafy throughout: herbage exceedingly fragrant, densely clothed with a nearly pure white tomentum which completely masks the striae of the stem and extends even to the involucres: leaves 1 to 3 cm. long, about 1 but sometimes nearly 2 mm. wide: inflorescence a rounded often compact cyme: involucre 6 to 7 mm. high; bracts very obtuse, plainly keeled and in 5 distinct vertical ranks, woolly but not ciliate: corolla 6.5 to 8 mm. long; tube more or less cobwebby with loose hairs or these occasionally wanting; lobes ovate, acute, strictly erect, 0.5 to 1 mm. long.

The type of *hololeucus* came from Owens Valley, California, whence we now have collections from a number of stations. What appears to be the same form occurs as far south as Antelope Valley and very good *hololeucus* grows as far north as Pyramid Lake, Nevada, but it does not have a wide east-and-west range. It is confined to loose gravelly or sandy well drained slopes and even in such places it never forms pure stands but occurs as scattered individuals among bushes of other sorts, commonly *C. n. gnaphalodes* and *Artemisia tridentata.* The plants are so white in comparison with these other shrubs that they can be distinguished in the field without difficulty.

3. **Chrysothamnus nauseosus** var. **latisquameus** (Gray) comb. nov.
Bigelovia graveolens latisquamea Gray, Proc. Am. Acad., vol. 8, p. 645, 1873.

Shrub tall (perhaps rounded at top), leafy to summit: herbage white with a rather loose tomentum: leaves 2 to 5 cm. long, less than 1 mm. wide: inflorescence a loosely branched rounded compound cyme: involucre about 8 mm. high (7 to 9 mm.); bracts carinate, about 4 in each of the 5 distinct vertical rows, outermost ones tomentulose, inner ones very obtuse and usually glabrous: corolla about 9 mm. long; tube short-pubescent or glabrous; lobes ovate or short-lanceolate, 0.4 to 0.9 mm. long, erect.

A common variety of New Mexico and Arizona. *Bigelovia graveolens appendiculata* Eastw., Proc. Calif. Acad. Sci., ser. 3, vol. 1, p. 74, 1897, from the White Sands of New Mexico, is an abnormal form with one to four linear appendages on the corolla-tube. The tube is arachnoid-pubescent and the lobes are only about 0.4 mm. long, both of which characters suggest an affinity with *hololeucus*. *C. arizonicus* Greene, Pitt., vol. 4, p. 42, 1899, is a form with the corolla-tube "cleft rather deeply." The type is from the Santa Rita Mountains.

4. **Chrysothamnus nauseosus** var. **salicifolius** (Rydb.) comb. nov.
Chrysothamnus salicifolius Rydb., Bull. Torrey Club, vol. 37, p. 130, 1910.

Shrub 3 to 10 dm. high, with erect branches: leaves 3-nerved, 4 to 8 cm. long, 3 to 6 mm. wide, minutely tomentulose: inflorescence cymose, dense: involucre 7 to 8 mm. high; outer bracts slightly tomentulose, the inner glabrous and very obtuse: corolla about 10 mm. long; lobes 1.5 to 2 mm. long.

Apparently a rare variety and confined to Utah; known to the writer from only two collections, namely, Strawberry Valley, at 7000 feet altitude, F. E. Leonard, no. 288 (type), and near Salt Lake City, A. O. Garrett, no. 2455.

5. **Chrysothamnus nauseosus** var. **gnaphalodes** (Greene) comb. nov.
Chrysothamnus speciosus var. *gnaphalodes* Greene, Eryth., vol. 3, p. 110, 1895.

Shrubs 5 to 15 or rarely 25 dm. high, usually globoid in outline, with very many short twiggy branches, not densely leafy: herbage very fragrant, gray with a closely packed tomentum, the twigs obscurely striate: leaves 2 to 4 mm. long, 1 mm. or less wide, those of the end twigs only 1 to 3 cm. long and often recurved: inflorescence a rounded cyme terminating each of the twigs: involucre about 7 mm. high; bracts rather obtuse, keeled, in 5 distinct vertical rows, tomentose, not ciliate: corolla 7 to 8 mm. long; tube sparsely pubescent with short crisp or rigid hairs; lobes ovate, acute, erect or even connivent around the stamen-tube, 0.5 to 1 mm. long.

This is the common gray variety of gravelly or sandy non-alkaline slopes and benches of western Nevada and eastern California from Pyramid Lake south to the Cajon, Soledad, and Tehachapi passes, and to Arizona. It belongs especially to the loose soil of well drained slopes surrounding valleys the alkaline bottoms of which are occupied by *viridulus,* and often forms belts of considerable extent. It is the most common shrub on land from which sagebrush has been burned or otherwise cleared, and is subclimax to that abundant shrub.

6. **Chrysothamnus nauseosus** var. **occidentalis** (Greene) Hall
Univ. Calif. Publ. Bot., vol. 3, p. 60, 1907.

Chrysothamnus californicus occidentalis Greene, Eryth., vol. 3, p. 112, 1895.

Shrub probably rather low, with numerous short slender erect branches, the leafy stems gray-tomentose but not loosely or flocculently so: leaves narrowly linear, 4 cm. or less long, mostly less than 1 mm. wide, but occasionally up to 2 mm., 1-nerved, tomentulose: inflorescence compactly cymose, rounded, 2 to 5 cm. across: involucre 7 to 9 mm. high; at least some of the bracts abruptly acute or cuspidate, the outer ones more or less glandular-puberulent: corolla 8 to 9 mm. long; lobes lanceolate-linear, 1.7 to 2.5 mm. long.

The distribution of this variety was originally stated by Greene to be "In the Coast Range, from Humboldt County (California) southward." Later, this same author stated it as "Kern and Santa Barbara counties."[4] This restriction in the adopted range was perhaps due to the fact that certain specimens from Humboldt and other northern counties do not meet the requirements of the description as well as those from further south. The cuspidate bracts and long corolla-lobes, together with the habit (especially the small compact rounded inflorescence), are here taken as the most satisfactory characters for the variety. Accepting this definition, we find fairly typical collections from the dry inner north Coast Ranges and from the southern Sierra Nevada and San Bernardino Mountains. North and east of Trinity County it apparently passes into *speciosus,* from which it scarcely differs save in the more nearly glabrous and abruptly pointed bracts. At its southernmost stations it meets and perhaps merges into *bernardinus.*

The following are taken as typical: near summit of South Yolla Bolla, Trinity(?) County, October, 1916, Merriam and Bailey; Little Kern River, Tulare County, C. A. Purpus, no. 2040; Barton Flats, in the San Bernardino Mountains, Mrs. Wilder, no. 597 (corolla up

[4] Greene, Fl. Fr., 1897, p. 369.

to 10 mm. long). *C. tortuosus* Greene, Pitt., vol. 5, p. 63, 1902, is aparently a form intermediate between this and *speciosus*. It is described as having tortuous flowering branches, nearly filiform more or less spreading leaves which are also tortuous, and rather pungently acute bracts. The types came from Plumas County and Mount Shasta, California.

7. **Chrysothamnus nauseosus** var. **speciosus** (Nutt.) comb. nov.

Chrysothamnus speciosus Nutt., Trans. Am. Philos. Soc., ser. 2, vol. 7, p. 323, 1841.

Shrub commonly 6 to 20 dm. high, broad and rounded, leafy to summit: twigs greenish white, the tomentum comparatively thin and smooth: leaves 2 to 6 cm. long, typically about 1 mm. wide but varying to 3 mm., usually erect or ascending, becoming dense towards the inflorescences and there scarcely reduced in size, gray, tomentose or the tomentum partly deciduous and the foliage then greenish: inflorescence a round-topped or somewhat elongated cyme, commonly loose: involucre 7 to 10 mm. high; bracts 3 or 4 in each row, acute, concave, tomentulose on the back, not ciliate: corolla 8 to 10 mm. long; tube sparsely puberulent or glabrous; lobes 0.8 to 2 mm. long.

The above description is drawn to include a number of forms. In this broad sense *speciosus* has a range from Idaho and Utah to California and Washington. It is a variety belonging to sandy slopes and benches with little or no alkali. The type came from "the Rocky Mountain plains, near Lewis River" and was described as having narrow, linear, acute, more or less tomentose leaves and heads in dense, conglomerate, terminal clusters. A form which answers to this but with a slightly elongated and loose inflorescence is common from northern Utah to eastern Oregon and northern California where, through the nearly glabrous character of the involucre it passes into *occidentalis*. Further south in eastern California and western Nevada the involucre becomes more compact and nicely rounded but in this form the comparatively rigid leaves are 2 to 3 mm. wide and vary from gray to yellowish green. This type was apparently included by Dr. Greene in his *californicus*. In the absence of better characters and with our scant knowledge of the real *speciosus* it seems unwise to segregate these forms more definitely at present, although they are more striking than many of the Rocky Mountain varieties accepted in this paper. *C. pulcherrimus*, A. Nels., Bot. Gaz., vol. 28, p. 370, 1899, is a form of the high plains of the Rocky Mountain states, especially in moist soil. All of the characters used to differentiate it from *speciosus* are variable and no two of them vary in unison, but

the more nearly glabrous nature of the involucre seems to be the most important. As pointed out by Dr. Nelson, it also resembles *graveolens*, but the narrower leaves are constantly one-nerved and the involucre is not absolutely glabrous. *C. pulcherrimus fasciculatus* A. Nels., l.c., is described as having numerous short branchlets and numerous rigid leaves only 2 to 3 cm. long. It has been collected at Boulder Creek and at Creston, both of these localities being in Wyoming.

8. **Chrysothamnus nauseosus** var. **frigidus** (Greene) comb. nov.

Chrysothamnus frigidus Greene, Eryth., vol. 3, p. 112, 1895.

Sub-shrub woody only at the base, often nearly prostrate, 2 to 6 dm. high, with mostly erect stems, very leafy: twigs whitish with a smooth close tomentum: leaves 2 to 5 cm. long, 1 to 1.5 mm. wide, mostly erect or ascending, white-tomentose: inflorescence cymose or elongated: involucre about 7 mm. high; bracts tomentulose and somewhat glandular, ciliolate at least at summit: corolla 6 to 7 mm. long; tube puberulent; lobes linear-lanceolate, 1.2 to 1.5 mm. long.

This variety belongs to the elevated bleak plains of the Rocky Mountain states, is especially common on the Wyoming plateaus, and is said to occur as far north as Alberta. In one collection (Aven Nelson, no. 2787, from Laramie) the corolla-tube is well provided with a long loose cobwebby pubescence, just as in the otherwise very different *nauseosus* proper and in *hololeucus*. *C. frigidus concolor* A. Nels., Bot. Gaz., vol. 28, p. 371, 1899, is a form with yellowish green herbage and somewhat elongated inflorescences. It grows in sandy more or less alkaline soil in Wyoming and Montana. *C. pallidus* A. Nels., l.c., p. 372, is a form also allied to *frigidus* and perhaps to be united with it. The twigs are less leafy except near the top, where they are shorter and more crowded; the herbage is nearly white with a close persistent tomentum. It inhabits alkaline soil in Wyoming and northern Colorado.

9. **Chrysothamnus nauseosus** var. **plattensis** (Greene) comb. nov.

Chrysothamnus speciosus(?) plattensis Greene, Eryth., vol. 3, p. 111, 1895.

Characters as given for *frigidus* except that the narrower leaves are loosely spreading or even recurved and that only the outer bracts are tomentulose.

A form of the alkaline plains along the eastern base of the Rocky Mountains. The type was described as having rather densely woolly-ciliate bracts but in most collections the bracts are only obscurely

ciliate. Since also the direction assumed by the leaves is not constant, this variety is exceedingly unstable and probably represents an ecologic form.

10. **Chrysothamnus nauseosus** var. **bernardinus** var. nov.

Shrub leafy to the summit: annual twigs strict, about 3 dm. long, coated with a smooth gray pannose tomentum, not striate: leaves ascending, linear, 3 to 5 cm. long, 1 to 2 mm. wide, mostly conduplicate, 1-nerved, very acute, often recurved at tip, green and scabro-puberulent: inflorescence a loose rounded cyme, 3 to 5 cm. across, the lower branches 2 to 6 cm. long: involucre 5-flowered, cylindric-turbinate, about 12 mm. high; bracts in well-defined ranks, 4 in each rank, keeled, thin, stramineous, lanceolate (the short outermost ones ovate), sharply acuminate, glabrous or slightly erose-ciliate or the outer ones obscurely puberulent: corolla 9 to 10 mm. long; tube sparsely crisp-puberulent; lobes linear-lanceolate, acute, 1.8 to 2 mm. long: anther-tips acute, about 0.5 mm. long: style-branches about 4 mm. long, stigmatic about one-half their length: akenes densely sericeous-pubescent: pappus soft, about 8 mm. long, becoming pink.

Frutex undique foliosus: ramulis horotinis strictis non striatis, ca. 3 dm. longis, tomento pannoso cinereo vestitis: foliis ascendentibus, linearibus, 3–5 cm. longis, 1–2 mm. latis, plerumque complicatis, 1-nerviis, acutissimis, apice saepe recurvatis, viridis, scabro-puberulis: inflorescentia cymam rotundam laxifloram formante, 3–5 cm. latam, ramulis inferioribus 2–6 cm. longis: involucris 5-floris, cylindrato-turbinatis, ca. 12 mm. altis; squamis distincte seriatis in utraque sericri verticali 4, carinatis, tenuibus, stramineis, lanceolatis (exterioribus brevioribus ovatis), acuminatis, glabris, nunc parce eroso-ciliatis nunc exterioribus obscure puberulis: corolla 9–10 mm. longa; tubo parum crispo-puberulo; lobis lineari-lanceolatis, acutis, 1.8–2 mm. longis: antheris apice acutis, ca. 0.5 mm. longis: styli ramis ca. 4 mm. longis, parte stigmatice duplo longioribus: achaeniis dense sericeo-pubescentibus: pappi setis tenuibus, ca. 8 mm. longis, colore deinde roseis.

Dry, open hillside at 7400 feet altitude, Bluff Lake, San Bernardino Mountains, California, September 2, 1905, Joseph Grinnell (Herb. Univ. Calif. no. 149208), type. As far as known, this variety is confined to the San Bernardino and San Antonio mountains of southern California. The specimens cited below exhibit the following variations: cyme up to 10 cm. in diameter and the lower branches 10 cm. long: involucre 10 to 13 mm. high, occasionally six-flowered. Because of the frequent longitudinal folding of the leaves, these structures often appear much narrower than they really are. This applies to the type as well as to most of the other specimens cited.

In addition to the type, the following collections apparently belong here: Little Bear Valley, San Bernardino Mountains, Mrs. C. M. Wilder, no. 740; Little Green Valley, San Bernardino Mountains,

Geo. R. Hall, no. 34; Pine Mountain Ridge, San Antonio Mountains, I. M. Johnston, no. 1652; rocky hillsides of Round Valley, San Jacinto Mountain at 9000 to 9500 feet altitude, H. M. Hall, no. 341. In this last mentioned collection the compact cymes are only 3 to 4 cm. across, the anther-tips are 1 mm. or more long and very slender, the style-branches are fully exserted and 4 to 6 mm. long. A detailed study of fresh material may demonstrate that it is a variety distinct from *bernardinus,* but the specimens at hand are too meagre to justify this.

The variety *bernardinus* is somewhat like *occidentalis* but with a larger and looser inflorescence, longer involucres and flowers, and thinner tegules which are gradually acuminate instead of abruptly pointed. In most of its characters, as well as in the appearance of herbarium specimens it almost duplicates the Rocky Mountain *pulcherrimus,* here referred to var. *speciosus,* but the involucre is longer and the more strongly keeled bracts are acuminate instead of merely acute. Moreover the geographic isolation of *bernardinus* argues for its recognition as a variety distinct from *pulcherrimus.*

11. **Chrysothamnus nauseosus** var. **Bigelovii** (Gray) comb. nov.

Linosyris (*Chrysothamnus*) *Bigelovii* Gray, Pacif. R. R. Rept., vol. 4, no. 4, p. 98, 1857.

Shrub densely branched, 3 to 10 dm. high: twigs short, leafy, yellowish green with a closely packed tomentum: leaves linear-filiform, 1 to 3 cm. long, tomentulose when young: inflorescence a lax few-headed cyme terminating each of the branches: involucre 10 to 12 mm. high; bracts 4 or 5 in each row, tomentulose and sometimes ciliate, attenuate, spreading in age: corolla 8 to 9 mm. long; lobes ovate, erect, 0.5 to 0.8 mm. long: akenes glabrous.

The variety *Bigelovii* is a form from the very dry plains and hills of the southern Rocky Mountain region and southward to Texas. It has been classified near to *C. pulchellus* but the brittle striate twigs and divaricate branching of that species indicate for it an entirely different origin. Moreover, the loose involucres of *Bigelovii,* with bracts in only obscurely vertical ranks, are very unlike those of the *Pulchelli.* It is plainly a variant of *nauseosus,* and its nearest affinity will probably be found in var. *leiospermus,* from which it differs chiefly in the very pubescent and acute bracts. Specimens gathered in southeastern Utah by Rydberg and Garrett (nos. 9435, 9940) are intermediate, having the essentially glabrous involucres of *leiospermus* but with bracts which are almost as sharp as in *Bigelovii.*

12. **Chrysothamnus nauseosus** var. **glareosus** (M. E. Jones) comb. nov.

Bigelovia glareosa M. E. Jones, Zoe, vol. 2, p. 247, 1891.

Shrub many-stemmed, said to be only about 3 dm. high: leaves broadly linear, slightly widened above, plane: inflorescence cymose: bracts about 4 in each vertical row, somewhat keeled, obtuse, sparsely erose-ciliate, scurfy-tomentulose: corolla about 12 mm. long; lobes linear-lanceolate: akenes glabrous.

This variety is apparently restricted to central and southern Utah, where it grows on gravelly mesas. It was originally compared with *leiospermus,* from which it differs in the tomentulose involucre and other characters.

13. **Chrysothamnus nauseosus** var. **leiospermus** (Gray) comb. nov.

Bigelovia leiosperma Gray, Syn. Fl., vol. 1, part 2, p. 139, 1884.

Shrub low (3 to 12 dm. high), with numerous short erect twigs, these either moderately leafy or almost naked: twigs yellowish green with a very close tomentum: leaves filiform or nearly so, acute, mostly 0.5 to 2 or 3 cm. long, essentially glabrous: heads in close terminal cymes of 2 or 3 cm. diameter: involucre 6 to 8 mm. high: bracts linear-oblong except the short ovate outer ones, obtuse, glabrous: corolla 5 to 8 mm. long, the tube very obscurely pubescent (or glabrous?); lobes ovate, erect, glabrous, 0.5 mm. or less long: akenes completely glabrous in the typical form but often sparsely pubescent, especially along the prominent nerves.

This form inhabits the most arid portions of the Great Basin, growing mostly on very dry exposed hillsides or in dry rocky streamways. The only collections seen by the writer are from Clear Creek Cañon, Utah, Candelaria in western Nevada, and Caliente in eastern Nevada. The Clear Creek specimens formed the basis of *Bigelovia leiosperma* var. *abbreviata* M. E. Jones, Proc. Calif. Acad. Sci., ser. 2, vol. 5, p. 693, 1895, a form with scant tomentum and leaves 1 cm. or less long. The Caliente specimens (H. M. H., nos. 10791, 10795) represent an extremely xerophile type of very dry exposed hillsides in the Lower Sonoran Zone. Their stems are green and rush-like, and the leaves reduced to scales about 3 mm. long, or rarely developed and then about 1 cm. long. In one of the Caliente specimens the akenes are very sparsely pubescent on the edges; in another from the same station they are sparsely pubescent also on the intervals. This indicates that the absence of pubescence cannot be satisfactorily used as a specific character. The relationships of *leiospermus* are probably with *Bigelovii.*

14. **Chrysothamnus nauseosus** var. **graveolens** (Nutt.) Piper. Contr. U. S. Nat. Herb., vol. 11, p. 559, 1906.

Chrysocoma graveolens Nutt., Gen., vol. 2, p. 136, 1818.
Bigelovia graveolens glabrata Gray, Proc. Am. Acad., vol. 8, p. 645, 1873.

Shrub robust, leafy to summit: twigs yellowish green to nearly white, more or less striate, the tomentum compact and smooth: leaves broadly linear, 1 to 3 mm. wide, mostly 3- or 5-nerved, impunctate, smooth and green but often slightly tomentulose, especially beneath: inflorescence a round or flat-topped cyme, fastigiate, the heads crowded: involucre 6 to 9 mm. high, glabrous: corolla 6 to 9 (rarely 10) mm. long; lobes 0.5 to 1 or rarely 1.6 mm. long, erect.

There can be little doubt that the original of Nuttall's *Chrysocoma graveolens* is the plant here described, for in the brief description are mentioned the linear, three-nerved, smooth leaves; the corymbosely fastigiate and crowded "flowers"; and the smooth, five-flowered, angular "calix." This is the common form in the easterly part of the range of the genus, especially in Wyoming, Colorado, and northern New Mexico. *C. virens* Greene, Pitt., vol. 5, p. 61, 1902, apparently is not to be retained even in the most subordinate rank. From the description it seems to be very near to *graveolens* but it is perhaps greener, the involucre only one-half as long as the flowers, and the bracts somewhat triangular. These characters are all extremely variable. Although the writer has searched for it at the type locality (Cañon City, Colorado) and in surrounding districts, no specimens were found that could be satisfactorily separated from *graveolens*. *C. laetevirens* Greene, l.c., described from material gathered at Grand Junction, Colorado, has been studied at its type locality. Apparently there is no reason for considering it more than a light-green form or state of *graveolens*.

15. **Chrysothamnus nauseosus** var. **californicus** (Greene) comb. nov.

Chrysothamnus californicus Greene, Eryth., vol. 3, p. 111, 1895, in part.

Shrub low and leafy-stemmed: twigs white with appressed tomentum, leafy to the summit: leaves broad (2 to 5 mm.), narrowly oblanceolate, 3-nerved, scarcely tomentulose but green and densely glandular: inflorescence minutely glandular, consisting of short terminal cymes: involucre 9 to 10 mm. high, 8 to 10-flowered; bracts thin, loose, only 2 or 3 in each vertical row, all lanceolate, attenuate, not tomentose but rather densely glandular: corolla about 10 mm. long; lobes 1.2 to 1.5 mm. long; tube puberulent (not arachnoid).

As here restricted, *californicus* is a rare sub-shrub of the high Sierra Nevada. Our description is drawn from Bolander's no. 6137 from Mono Pass at 9000 to 10,000 feet altitude. In the original description Greene combined with this a taller form with tomentulose leaves and inflorescence and 5-flowered heads, which form belongs to lower altitudes and is included in *speciosus* of the present synopsis.

16. **Chrysothamnus nauseosus** var. **ceruminosus** (Dur. & Hilg.) comb. nov.

Linosyris ceruminosa Dur. & Hilg., Pac. R. Rept., vol. 5, part 3, p. 9, pl. 6, 1856.

Shrub 5 to 12 dm. high, fastigiately branched, the stems yellowish green with a compact tomentum: leaves linear-filiform, 1 to 3 cm. long, tomentulose: inflorescence compactly cymose, rounded, 2 to 3 cm. across: involucre 7 to 8 mm. high; bracts thin, yellowish, abruptly narrowed to a filiform recurved mucro about 1 mm. long, glabrous and glutinous or apparently somewhat puberulent: corolla about 6.5 mm. long; lobes 1 to 1.7 mm. long.

Known from only two collections, namely, the type collection by Dr. Heermann somewhere near Tejon Pass, California, and one made by Mrs. Spencer in October, 1917, at Hesperia, a station on the Mojave Desert about ninety miles east of Tejon Pass.

17. **Chrysothamnus nauseosus** var. **oreophilus** (A. Nels.) comb. nov.

Chrysothamnus oreophilus A. Nels., Bot. Gaz., vol. 28, p. 375, 1899.

Shrub described as 2 to 4 dm. high with erect stems, very leafy to the top: twigs yellowish green, the tomentum thin and smooth: leaves 3 to 7 cm. long, about 1 mm. wide, strictly erect, the upper ones crowded and not reduced, all tomentulose at least when young but green: inflorescence composed of numerous small cymes in a more or less elongated but round-topped thyrse: involucre 7 to 8 mm. high; bracts carinate, acute, sparingly tomentulose, ciliolate: corolla 7 to 10 mm. long; tube crisp-pubescent; lobes linear-lanceolate, 1.3 to 2 mm. long.

This is an apparently rare plant of saline soils in Wyoming and Idaho. Its characters indicate that it may be a derivative of *graveolens* differing chiefly in the narrower leaves and much longer corolla-lobes. In the latter respect it resembles *consimilis,* into which more westerly form it probably intergrades. The more numerous and wider strictly erect upper leaves and the somewhat flat ciliate bracts may, however, serve to distinguish it from *consimilis.*

18. **Chrysothamnus nauseosus** var. **pinifolius** (Greene) comb. nov.

Chrysothamnus pinifolius Greene, Pitt., vol. 5, p. 60, 1902.

Shrub of medium size, with slender, very leafy stems: leaves linear-filiform, 1 mm. or less wide, 1-nerved, green to grayish puberulent, often densely tomentulose beneath: inflorescence a thyrsoid panicle of rounded or pyramidal outline, varying to short-oblong: involucre about 7 mm. long, glabrous: corolla 6 to 9 mm. long; lobes 0.5 to 1 mm. long.

Most abundant in Colorado but extending into adjacent states; replaced further west by *consimilis*. The characters separating this variety from *graveolens* seem to be correlated with the more vigorous growth of the latter and intermediate forms are common. *C. patens* Rydb., Bull. Torrey Club, vol. 31, p. 652, 1904, is a form of *pinifolius* with spreading and more or less falcate leaves, but this character is widely variable on single plants and moreover it does not vary in unison with other characters. The corolla-lobes in *pinifolius* are described as about 0.5 mm. long; those of *patens* as about 1 mm. long. However the lobes are not infrequently as much as 1 mm. long and occasionally even 1.4 mm. in plants otherwise typical of *pinifolius*. *C. confinis* Greene, Pitt., vol. 5, p. 62, 1902, of New Mexico, is scarcely separable from *pinifolius*. Its best characters lie in the rather obtuse and short-ciliate bracts, but even in *pinifolius* at least a portion of the bracts are more or less ciliate. *C. falcatus* Greene, l.c., based upon specimens collected on the plains about Grand Junction, Colorado, is *pinifolius* with the lower face of the leaves white-tomentose, as is commonly the case. Dr. Greene used also the curvature of the leaves and the angle made by them with the stem as differentiating criteria but field studies made by the author at Grand Junction indicate that such characters are much too variable, even in individual plants, to be of use. This is indicated by sheets nos. 203083 and 203177 at the University of California, under *graveolens*.

19. **Chrysothamnus nauseosus** var. **consimilis** (Greene) comb. nov.

Chrysothamnus consimilis Greene, Pitt., vol. 5, p. 60, 1902.

Shrub of medium or large size, the slender erect twigs very leafy: leaves ascending or spreading, nearly filiform, less than 1 mm. wide, 1-nerved, somewhat resinous and canescently tomentulose to nearly glabrous: inflorescence an elongated pyramidial or cylindric thyrsus: involucre 7 to mostly 8 or 9 mm. high; bracts not in distinct vertical rows, glabrous: corolla 7.3 to 8.3 mm. long; lobes 1 to 2 mm. long, spreading in age.

This is the common *Chrysothamnus* on alkaline flats of the Great Basin, especially in northern Nevada, whence it extends to Arizona, California, Oregon, and Idaho. In western Utah also it is the common alkali-flat form but easterly it merges both in characters and distribution into *pinifolius*. It may usually be distinguished from this form by the longer, more spreading corolla-lobes, and sometimes by the more elongated inflorescence. To the southwest of its range it passes into *viridulus*, as indicated under that variety. *C. angustus* Greene, Pitt., vol. 5, p. 64, 1902, described from specimens collected in northeastern California, is exactly the same. It was said to be distinguishable by its canescent "woolliness," but copious material from both type localities indicates that this character can be correlated neither with other characters nor with geographic distribution, and the amount of pubescence is of course variable. These remarks apply equally well to leaf-length, and no other differentiating characters appear in the descriptions.

20. **Chrysothamnus nauseosus** var. **viridulus** var. nov.

Shrub robust, green, about 1.5 m. high, leafy to the summit: twigs densely covered with pannose yellowish green tomentum, rather stout, striate: herbage malodorous: leaves at first erect or ascending, later inclined to droop, narrowly linear, 3 to 5 cm. long, about 1 mm. wide, acute, 1-nerved, channeled above, green but tomentulose on both sides: inflorescence a pyramidal to nearly globose thyrse: involucre 6 to 7 mm. high, glabrous but viscid with a resinous exudation; bracts 3 or 4 in each of the 5 vertical ranks, carinate, the outer ones acute, the innermost ones obtuse: flowers, 5: corolla 8.3 to 10 mm. long; tube glabrous or sparsely puberulent, passing gradually into the throat; lobes linear, acute, 2 to 2.5 mm. long, 0.4 mm. wide, recurving in age: anthers 3 to 3.3 mm. long, the tip 0.42 to 0.68 mm. long: akenes densely sericeous: pappus about 7.5 mm. long.

Frutex validus, viridis, ca. 15 dm. altis, undique foliosus: ramulis tomento luteolo-viridi dense vestitis, paullo robustis striatis, odore injucundis: foliis primum erectis vel ascendentibus, deinde flaccescere inclinantibus, anguste linearibus, 3–5 cm. longis, ca. 1 mm. latis, acutis, 1-nerviis, supra impressis, viridulis, utrinque tomentulosis: inflorescentia thyrsum globoso-pyramidatum formante: involucro 6–7 mm. alto, glabro, resinoso-viscido: squamarum seriebus verticalibus 5, in utraque serieri 3–4, carinatis, exterioribus acutis, interioribus obtusis: floribus 5: corolla 8.3–10 mm. longa, tubo glabro parce puberulo, infundibuliformi, lobis linearibus, acutis, 2–2.5 mm. longis, 0.4 mm. latis, deinde recurvatis: antheris 3–3.3 mm. longis mucrone 0.42–0.68 mm. longo: achaeniis dense sericeis: pappo ca. 7.5 mm. longo.

Benton, Mono County, California, on sandy alkaline flats with *Distichlis*, in the Upper Sonoran Zone, at 5640 feet altitude, Novem-

ber 3, 1917, H. M. H., no. 10642 (Herb. Univ. Calif. no. 203068), type. This is the common form on alkaline flats in southern Mono County and in Inyo County, California, and in western Esmeralda County, Nevada, although there are many slight variations from the type as described above. Almost every valley exhibits forms not exactly like those in any other. The variations are chiefly in habit, pubescence, leafiness, size and shape of inflorescence, shape of bracts, and length of corolla-lobes. The plants range in height from a few dm. to nearly 3 m., but are always taller than broad unless abnormal; the corollas vary from 8 to 10 mm. in total length; the corolla-lobes are seldom shorter than 2 mm., yet in two collections there are some flowers with lobes only 1.7 mm. long; although the involucres of the type are only 6 to 7 mm. long, they vary in other specimens to 8 or even 9 mm.; the mature papus is 7 to 9 mm. long. A dwarf form of the alkali flats of Antelope Valley is referred here provisionally. It has flexuous stems, short rounded inflorescences and exceptionally small flowers (commonly 6 or 7 in a head), but the flowers, although reduced in size, have the narrow elongated and spreading lobes of *viridulus*. More nearly typical specimens have been gathered in the San Antonio Mountains at an altitude of 8000 feet, I. M. Johnston, no. 1706.

As to relationships, *viridulus* is probably a southwestern derivative of *consimilis* (or vice versa), from which it differs in the larger corollas with longer lobes, the thicker, more robust and rigid twigs and leaves, the heavier and more rounded inflorescence, and the stronger odor of the herbage. These characters are far from constant at all stations. The length of corolla-lobe is the most satisfactory. Of twenty-seven collections taken throughout the established range of the variety, only five have corolla-lobes 2 mm. or less long; of twenty-two collections from the range of *consimilis* none exhibit corolla-lobes of over 2 mm. in length; where the ranges meet as around Mono Lake and at Sodaville, Nevada, intermediate sizes are frequent and here the other differentiating characters also intergrade. The very long corolla-lobes serve as a certain means of distinguishing *viridulus* from all other varieties except *consimilis, occidentalis, bernardinus,* and an occasional *mohavensis.*

21. **Chrysothamnus nauseosus** var. **mohavensis** (Greene) comb. nov.

Bigelovia mohavensis Greene, *in* Gray, Syn. Fl., vol. 1, part 2, p. 138, 1884.
Chrysothamnus mohavensis Greene, Eryth., vol. 3, p. 113, 1895.

Shrub of medium or large size, with many erect or ascending branches which are often nearly leafless and rush-like: leaves filiform, very acute, 1-nerved, nearly glabrous: inflorescence a rounded or somewhat elongated thyrse: involucre narrow, 9 to 10 mm. long, sharply 5-angled; bracts obtuse to acute, in very distinct vertical ranks, glabrous: corolla 8 to 10 mm. long; lobes 1.5 to 1.8 mm. long, spreading.

In this variety we have apparently a southern derivative of *viridulus*. It belongs to higher ground where the drainage is better and the soil not obviously alkaline. It skirts the westerly side of Owens Valley, California, extending southward to the slopes west of Antelope Valley and swings around the latter as far as the desert slopes of the San Bernardino Mountains. It occurs also at an isolated station on Mt. Hamilton, far out of its general known range, but the specimens at that station seem entirely typical and Dr. Greene, the first to detect the form, himself admitted them as *mohavensis*. The species will probably be found elsewhere along the hot inner South Coast ranges, a little-explored district where many species of the southern deserts extend their ranges northward.

Although first described as sparsely leafy or leafless this character cannot be relied upon since the tendency toward an early dropping of the leaves is common to the whole group. It is true, however, that *mohavensis* is more commonly leafless or nearly so. The naked wand-like branches are sometimes much elongated, in one case measuring 7.5 dm. without leaf or branch (H. M. H., no. 10570). The best characters lie in the involucre, which is mostly longer than in the other forms. Although the longest involucres of *viridulus* slightly exceed the shortest ones of *mohavensis*, yet the average of the former is about 7 mm., of the latter about 9 mm. The bracts are distinctly five-ranked and carinate, so that the involucre is sharply five-angled. They are somewhat obtuse but in some specimens which are referable here by all other characters the bracts are decidedly acute (H. M. H., nos. 9894, 10570, 10611, and Hall and Babcock, no. 5090).

As indicative of the gradation between *mohavensis* and *viridulus* may be cited a specimen from Oak Creek, along the west side of Owens Valley (H. M. H., no. 10611). The habit is that of *mohavensis* although some of the twigs were leafy when gathered on October 30.

The tegules are in very sharply defined vertical ranks, as in that variety, but they are even more acute than in *viridulus;* and the corolla-lobes are exactly intermediate in length, measuring 2.1 mm.

22. **Chrysothamnus nauseosus** var. **junceus** (Greene) comb. nov.

Bigelovia juncea Greene, Bot. Gaz., vol. 6, p. 184, 1881.
Chrysothamnus junceus Greene, Eryth., vol. 3, p. 113, 1895.

Shrub strict, fastigiately much branched, with slender rush-like mostly leafless yellowish green branches: leaves linear-filiform: inflorescence fastigiate-cymose: involucre about 10 mm. high, glabrous; bracts acute, 5 in each of the distinct vertical rows: corolla about 9 mm. long; tube pubescent but not arachnoid; lobes about 1.5 mm. long, externally beset with long delicate hairs.

This is a little-known shrub of eastern Arizona. It is described by Greene as "cinereous"; by Gray as "minutely canescent", but the twigs in the type have the usual pannose tomentum and all other characters indicate that it belongs to the present group. The pubescence of the corolla-lobes should be distinctive if constant.

FORMS NOT DEFINITELY PLACED

The following named species are all very close to *Chrysothamnus nauseosus* and at least some of them should doubtless be included in that species when taken in its broadest sense. However, they are not sufficiently well known to the writer to justify him in passing upon them at present.

Chrysothamnus formosus Greene, Pitt., vol. 4, p. 41, 1899. A low white shrub with narrow spreading foliage and wholly glabrous involucres with 6 or 7 bracts in each vertical row. Described from immature plants gathered "in the neighborhood of a mineral spring among the hills a few miles southwest from Grand Junction, Colorado."

Chrysothamnus Macounii Greene, Pitt., vol. 5, p. 63, 1902. Said by Dr. Greene to resemble *plattensis* and like it a low plant with white-tomentose twigs and very narrow spreading leaves. The type was from near Lytton, British Columbia.

Chrysothamnus moquianus Greene, l.c., p. 60. Described from imperfect specimens but seemingly a variety of *nauseosus,* perhaps one of those with glabrous akenes.

Chrysothamnus turbinatus Rydb., Fl. Rocky Mts., p. 859, 1917 (*Bigelovia turbinata* M. E. Jones, Proc. Calif. Acad. Sci., ser. 2, vol. 5,

p. 691, 1895). Said to be next to *junceus* and with the uppermost leaves reduced as in that form but with glabrous corollas. The bracts are five or six in each row and all obtuse or only apiculate. The type locality is Canaan Ranch, Utah.

IV. INDEX OF SPECIFIC AND VARIETAL NAMES

The numbers given in this index refer to the accepted variety in the foregoing synopsis, under which the name will be found.

UNIVERSITY OF CALIFORNIA PUBLICATIONS
IN
BOTANY

Vol. 7, No. 7, pp. 183-264, plates 18-20, 6 figures in text November 7, 1919

II. CHRYSIL, A NEW RUBBER FROM *CHRYSOTHAMNUS NAUSEOSUS*

BY

HARVEY MONROE HALL AND THOMAS HARPER GOODSPEED

CONTENTS

I. OBJECT AND SCOPE OF THE INVESTIGATION[1]

The investigation here reported upon was instituted for the purpose of locating a supply of rubber which it was thought might exist in certain native West American shrubs. Of all the various species originally considered, those belonging to the genus *Chrysothamnus*, commonly known as Rabbit-brush, seemed to be the most promising, and consequently they have received the most attention.

This work was undertaken immediately after the entry of the United States into the recent war and had for its incentive a consideration of the following facts: that rubber is absolutely essential to modern warfare; that it is the only war essential not now produced in this country; and that, therefore, we as a warring nation would be seriously handicapped in case the enemy should be able to carry out his threats and put a stop to our oversea commerce. This danger of interference with our importation of rubber has now been happily averted but since no one is able to state with certainty that it may not recur, the location of a native supply is still a matter of national concern. Our studies have therefore been continued somewhat beyond the duration of the war and have resulted, as indicated in the following pages, in the finding of rubber of good quality in some of our western shrubs. If it were all assembled the total amount (estimated to be over 300,000,000 pounds) would be considerable, but the percentage content of the plants is too small to warrant harvesting except under stress of national emergency. The very fact that the shrub is not rich in rubber may have its advantages when the matter is viewed from the standpoint of the nation's needs. It means that the rubber will not be subjected to commercial exploitation and will thus be preserved as an emergency supply to be drawn upon only in case we reach such straits that its utilization becomes necessary notwithstanding the high cost of harvesting.

The very best protection against the possibility of enemy interference with our supply would be the development of a permanent rubber-producing industry in this country. Aside from the manufacture of synthetic rubber on a commercially profitable scale—a desideratum which does not seem to give promise of early realization—our only

[1] This investigation was carried out chiefly by members of the Department of Botany of the University of California and was one of the projects of the Subcommittee on Botany of the Committee on Scientific Research of the State Council of Defense of California.

hope for this lies in the discovery and improvement of plants which can be grown in this country and which will be sufficiently productive to warrant their cultivation in competition with imported rubbers. One such species has already been introduced—Mexican Guayule (*Parthenium argentatum*), now being grown to a limited extent in southern Arizona. There is no assurance, however, that this plant can be profitably grown over a sufficiently large area to supply the country's needs in time of war, nor are we certain that it is the best one to be used. It is desirable that all promising sorts should be carefully investigated and their possibilities determined. These reasons have led to a broadening of the scope of our inquiry to include a preliminary study of the cultural possibilities of the plants under consideration.

This extension of the scope of the investigation has emphasized our deficiencies in time and facilities for the satisfactory prosecution of the work. Since it has been carried on thus far as a purely war emergency matter, the aim has been to assemble our information as rapidly as possible, and we have not permitted ourselves to become unduly engrossed in any phase of the work that seemed to require a long period of study or experimentation. The authors regret this keenly, since it means that the report here presented must be very incomplete; that many fundamental questions regarding both the scientific and practical aspects of the subject must go unanswered. It seems our duty, however, to place on record such data as we have, including particularly such information as will assist those who may interest themselves in a further search for rubber-bearing plants. Methods of carrying out the histological examinations and chemical analyses are for the same reason given in detail though they may prove neither novel nor instructive to the trained botanist and chemist. It is hoped that this report will serve as a basis for more intensive researches, either by ourselves or by others, when conditions are more favorable and that it will point the way to special investigations that have to do with the formation and occurrence of rubber in these West American shrubs and its possible utilization by man.

The preliminary studies here described have been in progress for about two years but the work was carried on only during vacation periods and in such additional time as could be spared from regular university duties. In addition we have profited by the generous assistance of numerous co-workers to whom acknowledgment is made below.

The discovery of rubber in *Chrysothamnus,* which was made about fifteen years ago, has been described by us in a recent paper[2] as follows:

> The choice of *Chrysothamnus* and related genera as the plants first to be investigated was the result of a preliminary examination made in 1904. In September of that year the late Judge A. V. Davidson, of Independence, Inyo County, California, sent some twigs to the Department of Botany for identification, with the information that the Indians prepared from the plant a sort of "gum" which they chewed. The plant was a species of *Chrysothamnus* of the *graveolens* group. Further samples were submitted at our request, and in October, 1905, a preliminary chemical examination of them was made by Professor G. E. Colby, of the California Experiment Station. This examination indicated the presence of rubber, but not in sufficient amount to warrant further investigation. A report to this effect was made public in the press and as a result some further examinations were made by at least one commercial rubber company. The matter was soon dropped, however. It is probable that the plants used in this commercial examination were of an entirely different species from those now being examined.

The examination of 1904 was followed with field work by the senior author in Inyo County in 1906, but no further chemical examinations were made. Professor Marcus E. Jones informs us that steps were taken about 1908 to erect a rubber-extraction plant at Salida, Colorado, the intention being to use Rabbit-brush but the plan fell through. He also tells us that as early as 1878 the Indians near St. George, Utah, taught some Mormon boys how to prepare rubber by mastication of the inner bark of these plants. It is evident that the Indians have long made use of the rubber as a chewing gum, but we have been unable to learn of any scientific study of the plants as rubber producers up to the time of our preliminary work in 1904.[3]

II. ACKNOWLEDGMENTS

Throughout the course of the investigation the authors have had the valuable co-operation of a considerable number of workers, some of whom have given largely of their time without remuneration. In the early stages of the work the chemical analyses were made by Professor Paul L. Hibbard, in the laboratory of the Division of Agricultural Chemistry of the California Exeriment Station and the staff of that laboratory, under the direction of Professor J. S. Burd, has given

[2] Science, n.s., vol. 47, p. 452 (May 10, 1918).

[3] Since the above was written word has come to us that a factory was in operation at Durango, Colorado, as early as 1905 and that the company in charge of it actually placed upon the market rubber made from "Rabbit-weed." However, the results of further inquiry indicate almost with certainty that the plant used was not *Chrysothamnus*, but the "Colorado Rubber Plant" (*Hymenoxys floribunda utilis*).

invaluable aid in the establishment and operation of our own laboratory, where the later analyses have been made by the junior author and Miss Mildred Crane. Dr. David Spence, Chairman of the Subcommittee on Rubber and Allied Substances of the National Research Council, has superintended the extraction and vulcanization of rubber from sample shrubs sent him and has given opinions from time to time regarding our methods and the quality of the product. Dr. W. B. McCallum, and Professor Francis E. Lloyd, both recognized experts on Guayule production, have made many valuable suggestions. Mr. E. C. McCarty of the University of California made a field trip of two weeks' duration into central Nevada for the purpose of collecting samples and making estimates as to the occurrence and distribution of certain species and Mr. J. R. Bruff, of the same institution, spent two weeks on such work in northern California and Nevada and southeastern Oregon. Professor Marcus E. Jones, of Salt Lake City, has performed a similar service in Utah. He spent a total of twenty days in the field and in addition has contributed freely from his very detailed knowledge of the botany and distribution of the shrubs throughout the Great Basin Area. Through the courtesy of Dr. Frederic E. Clements, of the Carnegie Institution of Washington, the senior author, was enabled to spend a month in field studies extending from Oregon to New Mexico. It is a pleasure to acknowledge also the assistance of Professor W. A. Setchell, head of the Department of Botany of the University of California, who has supported the work throughout both by his sympathy and advice and by making it possible for the authors to give to it a larger portion of their time than is ordinarily available for investigational work. The laboratories and herbarium of the Department of Botany have been freely used and much of the expense has been borne by the University. Grants have also been made, more especially for field expenses, by the Committee on Scientific Research of the State Council of Defense of California.

The list of friends who have sent information and samples, often at much trouble, includes the following: Mrs. Sidney Armer, Berkeley; Mr. W. W. Blakeslee, U. S. Forest Service; Mr. Fred E. Burlew, Los Angeles; Miss Ethel J. Case, Spokane; Mr. John Dondero, Mono Lake; Mrs. Roxana S. Ferris, Stanford University; Mr. M. French Gilman, Banning; Mr. Benj. J. Hoffner, U. S. Forest Service; Mr. Edmund C. Jaeger, Palm Springs; Mr. Geo. C. Larsen, U. S. Forest Service; Mr. W. M. Maule, U. S. Forest Service; Mr. James W. McGowan, U. S. Forest Service; Mr. Alexander McQueen, U. S. Forest

Service; Mr. Geo. E. Moore, U. S. Forest Service; Mr. R. C. North, McGill, Nevada; Mr. S. B. Parish, San Bernardino; Mr. George Park, U. S. Forest Service; Mr. W. O. Sauder, Center, Colorado; Mr. L. S. Smith, U. S. Forest Service; Mr. O. P. Stilwell, Ogden, Utah; Mr. J. Sutcliff, Sutcliff, Nevada; Professor J. J. Thornber, University of Arizona; Mr. H. B. Way, Montello, Nevada; Professor A. O. Weese, University of New Mexico; Mr. Kirk Whited, Redmond, Oregon.

For courtesies extended in connection with the field experiments, chiefly through the granting of the use of land and assistance in fencing, we are indebted to Messrs. George R. Shuey, Independence, California; W. H. Davis, Benton, California; and Eugene L. Dutertre, Golconda, Nevada.

To all of those who have assisted in the work, the authors tender their sincere thanks.

III. NATURE AND PROPERTIES OF CHRYSIL

Chrysil is the name here proposed for the rubber prepared from any form of *Chrysothamnus nauseosus.* It was suggested by Dr. Frederic E. Clements and is selected because of its euphony and brevity as well as for its suggestion of the botanical name of the plants from which the rubber is obtained. "Chrysothamnus" in turn, is derived from two Greek roots signifying "golden" and "wood."

The first samples of Chrysil were prepared for us by mastication from shrub of the *viridulus* form by Paiute Indians at Benton, California. These pieces were in the form of cylinders three-fourths to one inch long by about three-eighths of an inch in diameter. They included, in addition to the rubber, small amounts of resin, fiber, and other impurities. They were brown in color, firm, scarcely if at all tacky, and seemed to possess considerable strength and elasticity. Two experts accustomed to the handling of crude rubbers declared them to be "of good quality and considerably better than rubber prepared from Guayule." These samples were exposed to air and light and underwent a gradual change, so that at the end of a year they were black in color and quite tacky on the surface, these changes doubtless being due to impurities.

Twenty-five pounds of *viridulus* shrub were gathered from the flats at Benton and shipped to Dr. David Spence, Chairman of the Subcommittee on Rubber and Allied Substances of the National Research Council, with the request that he prepare rubber from it and

report on the yield and the quality of the product. The samples of shrub consisted of plants cut off a short distance below the surface of the soil and with all growth of less than three years removed; in other words, they consisted of those portions which would presumably be utilized in commercial operations. Dr. Spence very kindly undertook to make the examinations, and reports as follows regarding the preparation of the rubber and its properties:

In preparing the samples for analysis the woody ones were ground up on a pair of corrugated rolls, or a "cracker," and the bark samples were ground up and sheeted out on a smooth roll. It is interesting to note that the bark forms a smooth sheet on the mill.

Each of the four samples was placed in a bottle, covered with 100% benzol and shaken one hour. It was then allowed to stand twelve hours and the liquor drained off. This washing was repeated twice. After allowing the small dirt to settle out, the three combined washes were distilled to a small bulk, 400 to 500 cc. The rubber was coagulated from this concentrated solution by the addition of pure methyl alcohol. The coagulated mass of rubber was kneaded in fresh methyl alcohol and vacuum dried at 95°C. The dried rubber is dark brown in color, has very little tackiness and considerable elasticity. When the solvents are removed by boiling in water, a very tacky rubber results.

A larger sample of bark from both stems and branches was extracted and the rubber obtained was compounded as follows: rubber 100 g., zinc oxide 100 g., accelerator 3 g., sulfur 6 g. This compound was then divided into five portions and these were vulcanized for thirty minutes, sixty minutes, ninety minutes, two hours, and three hours, respectively. Forty pounds of pressure was applied in each case. The sixty minute treatment under forty pounds was full cure.

These samples[4] indicate that the rubber vulcanizes readily and gives a product of a very fair quality. I have no hesitation in committing myself as to its value as far as it is possible to estimate this from such small samples as I was able to obtain. In order to report on the exact commercial value of this rubber it would be necessary to make many more tests and much more exhaustive ones, but from the small samples I sent you I can already safely say that the rubber is of high grade and average quality. It is not as good as the best fine Para, but it is a great deal better than most Africans or low grade rubbers. The results would indicate that the bark of shrub No. 64 (that is *viridulus*) might well be investigated more extensively as a possible source of crude rubber existent in this country.

IV. BOTANICAL CLASSIFICATION; THE NAMES OF THE PLANTS

The plants in which rubber has been found during the course of this investigation all belong to two closely related genera of the Compositae, namely *Chrysothamnus* and *Haplopappus*. The latter is apparently of little importance, for although rubber has now been

[4] The five samples referred to by Dr. Spence are in the form of circular discs one-fourth inch thick by one and one-fourth inches in diameter. They are preserved in the Botanical Museum of the University of California.

found in ten of its species and in rather large amounts in two of these, yet the high-percentage species are small plants. This genus will be dealt with elsewhere.[5]

The other, that is, *Chrysothamnus,* is a West American genus of about sixteen major species, but these include so many variations that some botanists would recognize more than one hundred specific segregates. Eleven of the major species of *Chrysothamnus* have now been examined and rubber found in five of them. One of these, *C. nauseosus,* is of outstanding promise; the other four are discussed further on.[6]

Botanists are far from agreement as to the limitation of species in the genus, but for practical purposes it seems best to adopt a broad species concept and to recognize a considerable number of varieties under each of the species. According to this arrangement *Chrysothamnus nauseosus* constitutes a major species with twenty-two varieties. Twelve of these have been examined for rubber and it was found to be present in all of them. The complete botanical designation of each variety may be expressed by a trinomial, for example, *Chrysothamnus nauseosus* var. *graveolens; Chrysothamnus nauseosus* var. *viridulus,* etc., but for simplicity we may be permitted, in a special paper such as the present one, to omit the generic and specific names and refer to the various forms only by their varietal names. We shall, therefore, use such detached terms as *graveolens* and *viridulus* to express our concept of the respective varieties belonging to the very complex species known as *Chrysothamnus nauseosus.* It is hoped that this simplification will appeal to the non-botanical reader, who often has little time for and less interest in an involved taxonomic terminology and that it will, at the same time, meet the needs of the professional botanist. In some cases the name of a species itself will be used independently of its generic name. The exact taxonomic position of any variety of *Chrysothamnus nauseosus* may be determined by reference to pages 159 to 181.

The correct common name of *Chrysothamnus,* and more particularly of *C. nauseosus,* and its varieties is Rabbit-brush, a name which has been in use both among non-botanists and in botanical literature for at least twenty-five years. Through erroneous identification it has been frequently applied to other plants. In two publications it has been used indiscriminately[7] for species of *Chrysothamnus, Tetradymia,*

[5] See pp. 268–274.

[6] See pp. 265–268.

[7] N. Am. Fauna, no. 35 (1913), pp. 28, 31, 37; no. 42 (1917), pp. 79, 81.

and *Gutierrezia* and in a recent Experiment Station bulletin it has been adopted for *Tetradymia glabrata.*[8] But on grounds of usage as well as priority the term "Rabbit-brush" should be used only for species of *Chrysothamnus.* It is defined in this sense in three of the leading dictionaries used in America and also in some designed more especially for use in Europe. "Rabbit-brush" is given as the common name for *Chrysothamnus* in at least fifteen floras and technical reports and, so far as we can discover, it has never been defined either in dictionaries or in floras as belonging to any other plant. While there is considerable misapplication of the term by stockmen and other residents of the West, yet it is much more frequently applied to these plants than to any others. The name "Golden Bush" is used somewhat in the Rocky Mountain states. The undiscriminating sometimes fail to distinguish between these plants and Sage-brush, but the true Sage-brush (*Artemisia tridentata*) is a very different plant and may be recognized by the leaves, which are, for the most part, three-toothed at the summit, whereas in the Rabbit-brush they are always entire.

The Paiute name for any sort of *Chrysothamnus* from which rubber is prepared is *tsigupi* (pronounced tsē-gōō-pēē); or if the plant grows in sandy soil it is called *teba-tsigupi.* It is possible that the older Indians restricted the use of *teba-tsigupi* to some particular variety, but the younger generation is not so discriminating. Dr. A. L. Kroeber, who has indicated for us the proper spelling of these words, says that *teba* means "sun." According to Dr. David P. Barrows, the Coahuilla Indians of southern California call the *graveolens* form *tes-i-nit* and prepare from its twigs a tea taken for coughs and pains in the chest.

V. *CHRYSOTHAMNUS NAUSEOSUS:* HABIT, FLOWERING, RATE OF GROWTH, ETC.

All of the species of *Chrysothamnus* are shrubs. Some are mere dwarfs but those which interest us as possible rubber producers are usually of good size, measuring three to eight feet high, and about as broad. The rubber is present for the most part in those stem parts which are three years old or more, and these portions in average mature plants of the more important varieties (*viridulus, hololeucus,* etc.) will weigh from five to fifteen pounds (2.3 to 6.8 kg.). An exceptionally large plant found near Lone Pine, California, weighed sixty pounds ex-

[8] Nevada Experiment Station, Bull. 95 (July, 1918), pp. 2, 7.

clusive of the twigs, and shrubs weighing twenty to forty pounds are not rare. For purposes of estimate, however, much smaller figures must be used. This is partly because the plants reach the maximum size only under favorable conditions and partly because they are frequently burned or cut off near the base, after which new stems shoot up only to be again destroyed before reaching maturity. After weighing numerous samples and after making thousands of estimates in the field the authors believe six pounds to be a fair average weight of the woody portions of the *viridulus* variety as it grows in eastern California and western Nevada. This includes the root to a depth of only four inches (10 cm.). This estimate does not include young seedlings nor young second growth.

On a similar basis it is estimated that individuals of *consimilis,* the common variety in northeastern California, Nevada, and western Utah, will average five pounds, while variety *pinifolius* of Utah, southern Colorado, etc., will average four or five pounds.

The rubber producing kinds of Rabbit-brush all grow from deep taproots which have normally but few main laterals. There are usually several trunks from a single base and these are clothed in age with loose, fibrous brown bark which peels off in strips. Straight clear stems are the exception. The branches are usually numerous; they often exhibit many distortions and irregularities and are of unequal size. This has a bearing upon the possibility of decortication by machinery, a point of considerable practical importance. The rubber is carried chiefly in the inner bark and in the very outermost portion of the wood, so that decortication would greatly reduce the bulk and weight of the material to be extracted. The irregularities just mentioned would presumably render decortication by machinery impracticable as far as wild shrub is concerned. If the plants are brought under cultivation they would be more regular and uniform in their growth and the separation of the outer layers might then become feasible. According to Dr. D. Spence the bark could be very easily separated from the wood on a large scale even in irregularly shaped plants by soaking in hot, dilute, caustic soda solution. The young shoots are long, straight, and erect in *viridulus;* similar but shorter in *graveolens* and *consimilis;* very much branched and twiggy in *gnaphalodes* and *hololeucus*. In all of these forms they are covered with a closely packed gray, green, or white felt-like tomentum which is deciduous only after several years. The narrow entire leaves are rather sparse and may be either green, as in *consimilis* and *graveolens,*

dull green as in *viridulus,* or gray as in *gnaphalodes.* In typical *nauseosus* and in *hololeucus* the foliage is entirely covered by a beautiful soft and white woolly tomentum.

The flowers are yellow, very showy, and grow in heads arranged in dome-shaped to oblong clusters terminating the stems. The plants are therefore highly ornamental during the flowering season, which extends from August to October. At that time the large round-topped shrubs are crowned with a profusion of golden-yellow flower-clusters. As winter advances the flowers wither and fall, the foliage becomes more and more sparse, and finally only the naked gray or dull green twigs and empty involucres remain. The young twigs then die back for a considerable distance. But soon after the first winter rains or snows new shoots, springing from lateral buds well down on the year-old wood, form a new top to the plant. Since the die-back of the annual shoots does not extend to the base the general height, or level, of the old wood is increased each year. At the same time there is a thickening of all of the older stems through the addition of another annual layer of wood. The flowers of *Chrysothamnus,* which are very small and assembled into heads, as in all the Compositae, are much visited by honey bees and other insects. This assures cross-pollination and there is no evidence that the flowers are self-fertile. Seeds are set in abundance, and they show a high percentage of viability. These characters enable the plants to occupy quickly any suitable area that has been cleared of other brush.

The herbage of *Chrysothamnus* possesses a peculiar odor which varies somewhat with the different forms. The name *nauseosus* indicates that the type of that species was disagreeably scented but this we have not been able to verify. In *viridulus,* however, the green stems when broken emit a very strong, disagreeable odor, especially penetrating if they are burned in a closed room. On the other hand, when the twigs and foliage of *gnaphalodes* and *hololeucus* are broken in the hand the odor is exceedingly pleasant, suggesting a combination of tropical fruits and berries. It seems probable that this is due to the presence of a volatile oil which might have commercial possibilities if properly exploited, more especially as a by-product in case the plants are brought under cultivation for their Chrysil.

The age of full-sized shrubs is quite variable, depending upon the conditions under which the shrubs have grown and also possibly upon the botanical variety concerned. An estimate based upon counts of annual rings, places the average age of the more important kinds,

such as *viridulus* and *consimilis*. at about eight years. This is for plants weighing five or six pounds and growing in ordinary alkaline soil without attention or disturbance by man. Plants seldom reach full size before they are five years old and they often increase in weight up to ten years and perhaps longer.

VI. DISTRIBUTION AND HABITATS OF THE VARIOUS FORMS

Rubber producing varieties of wild Rabbit-brush are widely distributed in western North America. They belong to the Lower and Upper Sonoran life zones with slight extensions into the Transition, and range in altitude from about sea level in some of the desert basins, to 8000 feet in the southern Colorado mountains. Some varieties of *Chrysothamnus* occur at even higher altitudes but they have not been examined as to their rubber content. The plants are most abundant and of maximum size in the Great Basin area, becoming more and more scattered and apparently diminishing in their percentage of rubber as we pass outward from this center of distribution. The northern limits are reached in British Columbia, Alberta, and Saskatchewan, but no detailed studies have been made of plants from those districts. They probably contain rubber in only limited quantity and the areas covered by the shrub are not extensive. Our northern tier of states supports some *Chrysothamnus* but only in the more arid portions such as southeastern Washington and southern Idaho and Montana. The most northerly points from which we have taken samples for analysis are in eastern Oregon (Redmond, Burns, etc.), eastern Washington (Spokane), southern Idaho, and southern Wyoming (Rawlins, Laramie). The best samples carried only 3 per cent of rubber and most of them ran less than two per cent. This low yield may be due to the habitat or it may be that a larger series of examinations would show that we happened to select only low-grade individuals and that the average is really as high as in districts lying farther to the south.

The easterly limits of the genus are reached in South Dakota and western Nebraska; the southerly limits in western Texas, southern New Mexico, and southern Arizona, with some possible extensions into Mexico, or at least into Lower California. Analyses have not been made of plants from these outlying districts but the indications are that they are not good rubber producers. On the Pacific Coast we find

scattered groups of the plants as far west as the Coast Range mountains, for example, San Benito County, Mt. Hamilton, Lake County, Trinity County, etc. Four samples of *mohavensis* from Mt. Hamilton averaged only 0.53 per cent of Chrysil.

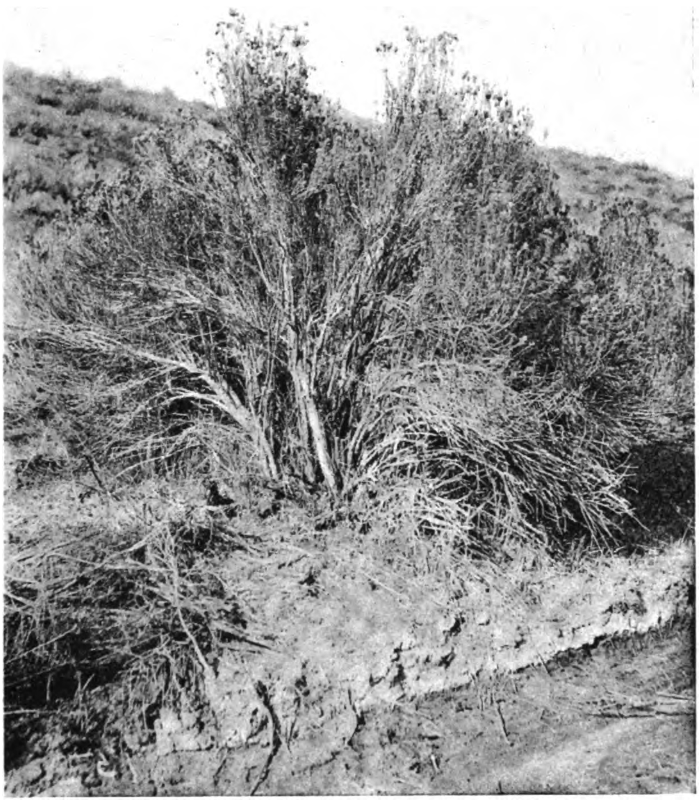

Fig. 1. *Chrysothamnus nauseosus* var. *viridulus*. Plant no. 468. Seven feet high; growing in alkaline soil with *Distichlis spicata* and *Iva axillaris*. *Artemisia tridentata* in background. Goat Ranch, north of Mono Lake, California.

Coming now to the more important areas centering around the Great Basin, we find that some of the densest stands and also the largest plants are found in the alkaline deserts of Nevada and eastern California. There are some large and important areas of the brush in southern Colorado and in Utah, but the plants in these states are not as good rubber producers as those farther west. Throughout the whole

area Rabbit-brush is confined to certain definite tracts ranging in size from a few square feet to about 800,000 acres. It is prevented from growing in other places, sometimes by unfavorable soil, moisture, or climatic condition; sometimes by the more aggressive habits of other species with which it is obliged to compete. For example, when the soil is very strongly alkaline it is either devoid of vegetation or supports such strongly alkali-tolerant species as Grease-wood (*Sarcobatus*), Pickle-weed (*Salicornia*), Sea Blite (*Suaeda*), and *Spirostachys*.

Where the alkali is somewhat less in amount but still too abundant for upland plants certain varieties of Rabbit-brush, particularly the green forms such as *viridulus, graveolens,* and *consimilis* become dominant and with Salt-grass (*Distichlis*), Poverty-weed (*Iva axillaris*), and similar plants cover areas of considerable extent. Here are found the most extensive and important stands of rubber-producing shrub and the percentage of rubber is fairly high. The soil is somewhat moist but too strongly alkaline for standard agricultural crops and since the native grasses and other forage and browse plants are of but little use to stockmen the value of the land is very slight. The removal of the Rabbit-brush would favor the growth of grazing plants, as has been demonstrated by our experiments. However, the brush would again assert itself in a few years unless held in check. If it is found practicable to grow Rabbit-brush for its rubber, these extensive tracts could be had at a very low price and without serious interference to any established industry.

Passing upwards from the alkaline flats just described one often comes to better drained and scarcely alkaline slopes. Here the Sage-brush (*Artemisia tridentata*) is usually dominant and forms the extensive brush-lands of the Great Basin area. It mixes more or less with the Rabbit-brush varieties mentioned above, but it is less alkali-tolerant and so yields to them on the lowlands. On the slopes and higher plains and especially in loose soil, or along dry water-ways, the Sage-brush is often mixed with or replaced by another series of varieties of *Chrysothamnus*. These are the gray forms, particularly *nauseosus, speciosus, gnaphalodes, hololeucus,* and *frigidus*. The green and the gray forms intermingle slightly where they meet in soils of moderate alkalinity and moisture, but the latter are much more intimately associated with Sage-brush. In the terminology of the ecologist, the Sage-brush is climax, the gray Rabbit-brush is subclimax. In other words if the former is disturbed by fire, trampling, washout, etc., it is replaced by the Rabbit-brush, which, however, is in turn

slowly crowded out by a new generation of the more aggressive Sagebrush. The result is that the gray forms are much more scattered than the green ones and almost never form pure stands of any great extent. They are sufficiently abundant in some places to yield a supplementary supply of rubber in case the green forms are harvested from near-by areas, but they should not be considered in making estimates of the total amount of native rubber available. Their chief interest lies in the fact that they are very erratic as rubber producers and might therefore furnish starting points in case experiments were undertaken in the breeding or selection of superior strains.

VII. ESTIMATES BY DISTRICTS OF THE AMOUNT OF CHRYSIL AVAILABLE IN WESTERN NORTH AMERICA

Although field studies on the occurrence and distribution of rubber-bearing shrubs have been carried on in all of the western states, actual estimates have been made for only a few of the areas upon which they are known to grow. The sudden termination of the war has removed the immediate need of a complete survey, but if an emergency call is ever made the work thus far completed will furnish a starting point for a definite estimate of the total amount obtainable as well as indicate the localities where it may probably be found in the largest quantities. Somewhat detailed estimates for the areas examined are therefore presented by districts.

This phase of the work has been carried on chiefly by the senior author, who has himself visited a majority of the areas reported upon and who assumes full responsibility for the estimates here given. His studies have been supplemented by those of a number of other botanists as mentioned on page 186.

The estimates were prepared in the following manner. Districts where the brush grows abundantly were visited and traversed when possible in several directions. Data thus accumulated, supplemented by such information as could be obtained from reliable residents, furnished rough estimates of the acreage covered, the percentage of vacant land within the area, and the ratio of Rabbit-brush to other shrubs. Small quadrats were then selected and the number of plants per acre determined. Average samples were weighed or at least estimated as to weight. From these data the total tonnage of shrub has been calculated. A sufficient number of samples has been analyzed

from widely separated geographic areas, and of the many botanical varieties to furnish something of a basis for the calculation of the total amount of rubber present on any given area, the total tonnage having been determined in the manner just described. While these results are far from satisfactory because of the meager data upon which they are based they will furnish at least a beginning in case more extensive investigations are inaugurated, and will indicate the best locations for rubber mills in case the government is ever obliged to resort to Rabbit-brush as a source of rubber in time of emergency.

The areas indicated in the following list include, we believe, most of those where Rabbit-brush is abundant, yet it is quite certain that at least a few large areas have escaped our hasty field survey. It is well known that, in addition, there is a multitude of small fields of the shrub and also that it often grows scatteringly where other species are dominant. However, because of the great expense of assembling shrub from small scattered fields, this source is not included in the estimates.

a. DISTRICT 1—EAST CENTRAL CALIFORNIA AND ADJACENT NEVADA

This district comprises Inyo and Mono counties in California, and an extension into Esmeralda County, Nevada, chiefly to include Fish Lake Valley. In it are found large areas of shrub carrying over 3 per cent of rubber, although the total area of shrub is much smaller than in some of the other districts where the percentage content is less. The chief variety included in the estimate is *viridulus,* which is larger, on the average, than any of the others. It occurs chiefly on the alkaline valley bottoms but ranges sparingly to altitudes of 7200 feet in alkaline soil. Mixing somewhat with it around the borders of the valleys, where the soil is better drained and less alkaline, are considerable quantites of *gnaphalodes, hololeucus,* and *mohavensis.* These extend well up the foothill slopes but always as mixtures in the Sage-brush climax—never as pure stands. North and east of Mono Lake, *viridulus* is replaced to some extent by *consimilis.* There is also a supplementary supply, furnished by the very considerable amount of *Chrysothamnus teretifolius,* a low shrub carrying about 2.7 per cent rubber; but since the plants are somewhat scattered it does not enter into our estimates (see p. 266).

Some of the best shrub in this district is found in Owens Valley, where it grows on most of the flats along the river; in an irregular strip along the Los Angeles aqueduct; and on isolated areas of from

one-half to several square miles in extent. Some of the largest plants seen anywhere grow near the aqueduct (but not irrigated from it) a few miles north of Lone Pine. The district around Keeler has not been examined, nor has Long Valley, although both are reported to have some Rabbit-brush. A considerable area in the lower part of Deep Spring Valley is also said to be covered with Rabbit-brush of the

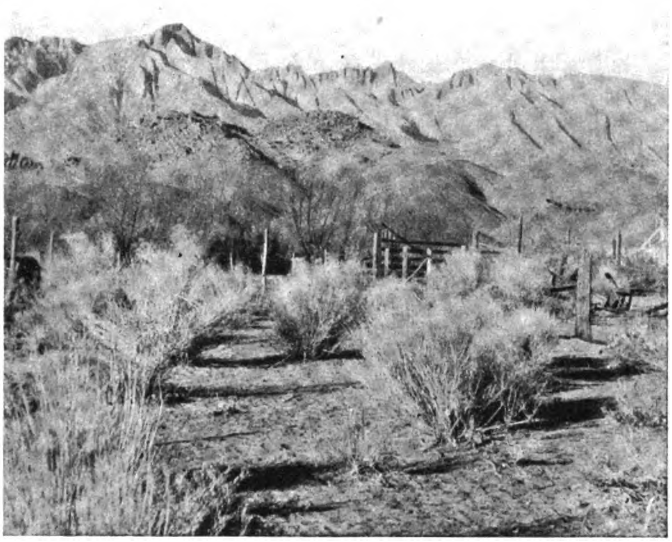

Fig. 2. *Chrysothamnus nauseosus* var. *viridulus*, mingling with var. *gnaphalodes*. Experimental tract, Lone Pine, California. Soil moderately alkaline, much trampled. Sierra Nevada Mountains in background; Mount Whitney at right of center.

viridulus variety. If harvested, probably the best place to take it for milling would be Owens Valley. Small lots are also obtainable to the northeast of Owens Valley, particularly in the vicinity of Benton, whence come our richest samples of *viridulus*, and in Chidago Cañon, etc. Our estimate of the total amount of rubber in Owens Valley and contiguous territory is 300,000 pounds.

Fish Lake Valley, in western Esmeralda County, Nevada, is included in District 1 since the size, habit, and variety of the shrub is similar to that around Mono Lake and in Owens Valley. The exact botanical classification of the plants, however, is not satisfactory. They

grow in varying degrees of density over most of the valley bottom except where farming operations have interferred. An estimate based upon a hurried visit in 1918 and upon data supplied by Forest Ranger George Parke places the total amount of rubber at 2,280,000 pounds.

Extensive areas of Rabbit-brush have been located in the vicinity of Mono Lake, but our analyses indicate that it is not so rich as that from Owens Valley and Benton. The principal varieties represented are *viridulus* and *consimilis*. There are about ten square miles of fairly large plants to the north and northeast of the lake in a nearly pure stand. On the south and southwest sides it is mixed with Sage-brush over an area of perhaps sixteen square miles. In Adobe Valley, which lies southeast of the lake, we find it in good formation from the Adobe Hills to the River Spring Ranch and in a narrower belt as far as Dutch Pete's while there are perhaps a thousand acres of it in a belt extending from Gaspipe to Indian Spring. By using the methods indicated above, we have estimated that these areas centering around Mono Lake would yield about 700,000 pounds of rubber.

The estimated total amount of rubber obtainable from District 1 is 3,280,000 pounds.

b. DISTRICT 2—MOJAVE DESERT, CALIFORNIA

This might almost as well be called the "Antelope Valley District" since it centers around this westerly arm of the Mojave Desert. It is not very promising as a rubber producer because of the large number of varieties represented and the consequent fluctuation in rubber content. The largest continuous area of shrub is a belt of *gnaphalodes* about two miles wide and perhaps thirty miles long, which extends diagonally across the valley in a northwesterly direction from near Palmdale to a point west of Rosamond. The shrubs are below medium size, the woody portion weighing on the average about three pounds, and there are about 50,000 plants per square mile. A similar belt is reported still farther west. These belts are undoubtedly due in large part to the burning off or clearing of the Sage-brush in the remote past and represent one stage in the succession which will ultimately bring this Sage-brush back as the dominant climax species. Analyses indicate that this shrub carries an average of two per cent of rubber. Smaller areas of *gnaphalodes* are scattered all around the borders of Antelope Valley and even to Tehachapi Pass and northward to Owens Lake, mixing slightly along its upper limits with *mohavensis*, but the lower, more alkaline lands support a scattered growth of what ap-

pears to be a dwarf form of *viridulus*. Most of these small plants carry less than two or three per cent of rubber and are of but little practical importance.

C. teretifolius, carrying about 2.7 per cent of rubber, grows sparsely on the Rosamond Hills but may be abundant on the mountains to the west of Antelope Valley. Around the borders of the Mojave Desert, especially toward the west, are scattered stands of two other low-grade rubber shrubs, *Haplopappus monactis* and *H. linearifolius,* but these are of little value.

The amount of rubber in the shrub which we have located in District 2, taking no account of the species mentioned in the preceding paragraph, is estimated at 400,000 pounds.

c. DISTRICT 3—NORTHEASTERN CALIFORNIA AND ADJACENT NEVADA AND OREGON

The principal areas thus far located in this district are on the alkaline plains of eastern Lassen and Modoc counties, California, where Rabbit-brush, in the *consimilis* form, makes pure stands over many thousands of acres. The percentage of rubber in these plants is apparently quite uniform and runs a little more than two per cent. There are about two square miles east of Honey Lake where the plants average sixteen feet apart and two representative samples weighed ten and twenty-eight pounds, respectively. In the vicinity of Karlo we find about seven square miles covered by a nearly pure stand of the shrub; an area of about the same size occurs on Painter's Flat; and still another to the west of Madeline. The plants on these tracts are often smaller than in the Honey Lake Valley (two taken near Karlo weighed under two pounds each for the woody portion), but when small they grow closer together. There is an area of 1000 acres south from Ravendale, covered with medium sized shrub. About twenty square miles have been located by Mr. L. S. Smith in northeastern Modoc County, where the Rabbit-brush comprises about 25 per cent of the vegetation, but it occurs chiefly in one of the gray-foliaged varieties and is therefore poor in rubber. There are some unexamined areas of *consimilis* west of Alturas, several sections of the gray form in Butte Valley and around Klamath Lake, and some extensive areas of *consimilis* on the Klamath River drainage of north-central Siskiyou County, California.

In southeastern Oregon, the Rabbit-brush was found by Mr. J. R. Bruff to exist only in small stands. The largest area located is in

Blitzen Valley, where there are perhaps twelve square miles of *consimilis,* and in Catlow Valley, where there is a somewhat smaller area of the same form. Studies made by the senior author from Burns to Bend and northward indicate that the plants there grow too sparsely to be of interest and that the percentage content is not uniform. Reports of large areas at Buffalo Meadows and on the Black Rock Desert of Nevada were found to be erroneous and it seems that there is but little of the shrub in the northwestern corner of that state. It is interesting to note, however, that two samples of the variety *consimilis* gathered along the edges of the alkali flats near Gerlach yielded the highest returns of all of the samples taken of *Chrysothamnus nauseosus.* They analyzed 4.71 and 6.57 per cent, respectively, of pure rubber.

The most important areas in this district are to be found, therefore, in eastern Lassen County, California, and in Blitzen and Catlow valleys of southern Oregon. The total amount of rubber in the shrubs thus far located in District 3 is estimated at about 1,000,000 pounds.

d. DISTRICT 4—WEST CENTRAL NEVADA

This small district lies wholly in Nevada and is between the California boundary and a line connecting Hazen and Tonopah. On the north it is limited by the line of the Southern Pacific Railway; on the south, by an east-and-west line passing through Tonopah.

The only variety of *Chrysothamnus* to be considered here as a possible source of rubber is *consimilis,* but this grows in abundance in valley bottoms where the soil is somewhat sandy, slightly moist, and, for the most part, too alkaline for Sage-brush. Around the edges of such areas, and running back into the hills, it is not uncommon to find other varieties, especially those of the gray types like *griseus, nauseosus,* and *speciosus,* but these occur as impurities in the Sage-brush consociation and are therefore too scattered to be of consequence as a possible source of rubber.

The *consimilis* form varies much in size and habit, depending in these characters upon soil and climatic conditions. Exceptionally large plants were encountered on the flats at the head of Walker Lake. These were six feet high and almost tree-like, with trunks five inches thick and over a foot in length to the first main branches.. Such plants have a weight of about thirty pounds, exclusive of twigs. The average weight of samples, however, taken from along Walker River, north of the lake is about ten pounds, while the average for the whole dis-

trict is nearer six pounds. The rubber content of seven samples taken at widely separated stations in the district averages 2.0 per cent and microscopic examinations of others indicate that there is not a wide fluctuation from this mean.

Fig. 3. *Chrysothamnus nauseosus* var. *consimilis*. Plant no. 216, Walker Lake, Nevada. Root two and three-eighths inches thick; trunk five inches thick at base of first branch; total height six feet; estimated weight about thirty pounds. This is an exceptionally large plant.

The southernmost areas of Rabbit-brush within this district are in Esmeralda County and lie along the Tonopah and Goldfield Railroad from Redlich nearly to Millers, one of them extending as a belt along the westerly side of the San Antonio Wash. Small areas of large brush were found at the upper end of Walker Lake, but much more import-

ant is the irregular belt which skirts the river on both sides from a point about nine miles above Schurz nearly to Wabuska, a distance of eighteen miles. This belt will average three-eighths of a mile in width; the plants are ten to twelve feet apart and have an average weight of about ten pounds. Forest Supervisor W. M. Maule reports about fifty square miles of shrub from Whiskey Flat north to Hawthorne; also about thirty-five square miles between Sweetwater and Fletchers. These areas are in western Mineral County. We have not ourselves visited them and have not had an opportunity to examine samples.

The Carson Valley and contiguous areas support about one-hundred and fifty square miles of Rabbit-brush of the *consimilis* form. Several other forms are present, some of them apparently devoid of rubber, but they grow scatteringly around the borders of the main bodies and extend up over the slopes as impurities in the sage-brush. It is on the lower, more nearly level, and alkaline flats of the valley that the best stands of *consimilis* are found. Here it often grows to the exclusion of other shrubs, and almost completely covers the ground with plants weighing three to five pounds.

According to our estimates, District 4 should yield at least 7,680,000 pounds of rubber, of which nearly one-half is in or near the Carson Valley. It is probable that further exploration would result in a considerable addition to this estimate.

e. DISTRICT 5—NORTHERN AND CENTRAL NEVADA

BY E. C. MCCARTY

This district comprises the counties of Humboldt, Leander, Eureka, Elko, White Pine, and a part of Nye County. In view of the many areas in this section which are favorable to the growth of *Chrysothamnus,* it would without doubt prove to be an important one in the production of an emergency supply of raw rubber. The long valley of the Humboldt River, extending through the counties of Elko, Eureka, Leander, and Humbolt, has many tributary valleys extending both to the north and to the south, and ranging from comparatively short valleys to valleys of more than fifty miles, the Reese River Valley being one of the longer ones.

The Reese River Valley, which is perhaps typical, is half a mile wide at Cañon, and more than fifteen miles wide at Austin. It extends the entire length of Leander County and into Nye County. The mountain range is continuous on either side of the valley and is marked at

frequent intervals by draws and gulches from which flow the streams tributary to the Reese River. This river has an interrupted flow through the greater part of the valley though it is itself a very small stream. The floor of the valley is comparatively level, and rises gradually to the mountains on either side. The altitude, which is four thousand five hundred feet at Battle Mountain, increases at the southerly end to upward of six thousand feet. The soil is alkaline and is of the type usually found in arid regions. The precipitation is meager; the greater portion probably occurs in the fall and winter. The summers are comparatively long and the number of days of sunshine in one year probably approaches three hundred. The coldest temperature experienced by the writer while in this valley during the month of December, 1918, was $-15°$ F.

The character of both soil and climate permits the growth of only drought-resistant vegetation. Generally speaking, the lowest lands of the valley floor are occupied by *Chrysothamnus,* while the more elevated portions are covered for the most part with *Artemisia.* Much of the lowlands is covered with pure stands of *Chrysothamnus.* Again large tracts occur in which this shrub represents fifty per cent of the entire stand. Along the river bottom the dominant shrub is *Chrysothamnus,* but in many places in the immediate vicinity of the stream the soil appears to be fairly moist in character, and is occupied by willows. In such sections, which are comparatively few, *Chrysothamnus* occupies the zone next to the willows and on either side of the stream. At many places in the valley the brush, in stands more or less pure, extends into the draws and gulches. Where the *Chrysothamnus* forms occur to the practical exclusion of other types, the stands are quite dense, the plants averaging from four to ten feet apart. It is believed that the pure stands occupy those parts of the valley in which the physiological drought of the soil reaches the maximum.

The pure stands of *Chrysothamnus* throughout the entire district are for the most part of the *consimilis* form. While there are some comparatively small areas of the gray varieties, these seldom occur in pure stands, and none of this type are included in the estimate for the district. The size of the green brush is variable. Some of the plants are quite large, the height being three to eight feet. While some of the larger ones would weigh as much as twenty-five pounds, it is not difficult to find others that would weigh still more. The average, however, is much lower, and the weights employed for the purpose of the estimates in this report are between two and seven

pounds. These figures, however, are based on the weight of a small portion of the root, and of the stems upwards of four years of age. Should it become desirable to use the younger wood the average weight would be increased by one to two pounds. It is probable that the amount of brush now available will remain constant for a number of years, since the character of the soil and climate is more favorable to stock raising[9] than to agriculture.

While many of the points in this district have been visited and are known to contain large tracts of *Chrysothamnus*, reliable information has been received in other ways relative to the occurrence of large stands in those sections which were not visited. The character of this information and the source whence it has come warrant the inclusion of these several areas in the estimate of available brush in the district. On the other hand the combined areas reported on and included in the estimate are but a part of the entire territory comprising the district. In view of the similarity in topography, in climate, and in soil conditions prevailing throughout this entire region it is believed that a more intensive survey of the district might reveal still other tracts of the shrub which in the aggregate would equal those included in this report.

The principal areas thus far located are the following:

Elko County: Ten Mile Flat; North Fork, Humboldt River Valley and tributary valleys; along the main line, Southern Pacific and Western Pacific railroads; Ruby Valley; along the Nevada Northern Railroad, Cobre to Goshute.

Eureka County: Along the main line, Southern Pacific and Western Pacific railroads; Antelope Valley.

Humboldt County: Areas lying 6 and 15 miles, respectively, northeast of Winnemucca; Rebel Creek; Quinn River Valley.

Leander and Nye counties: Along the main line of Southern Pacific and Western Pacific railroads; Reese River Valley; Big Smoky Valley (north end); Monitor Valley; Fish Spring.

White Pine County: Butte Valley; Long Valley; Newark Valley; Spring Valley; Steptoe Valley; White River Valley.

The total weight of Rabbit-brush known to exist in this district has been placed at 1,250,000,000 pounds. Twenty-three samples have been gathered and analyzed. The rubber content of these samples varies from 0.43 to 3.86 per cent, with an average of 1.89 per cent. On the basis of these figures the total available supply thus far located

[9] It is reported that *Chrysothamnus* is poisonous to range stock during the winter season.

would be 23,700,000 pounds of pure rubber. It must be borne in mind that these estimates are based on the weight of plants after the removal of the foliage and of all stems under four years of age.

f. DISTRICT 6—UTAH

Within the state of Utah, Rabbit-brush in several forms occurs over extensive areas, especially around the alkaline valleys of the central and southeasterly parts of the state. Much information as to the location of shrub in quantity has been assembled by Professor Marcus E. Jones, but an examination of the samples supplied by him indicates that the rubber content is less than that of plants from Nevada and California. The analyses we have made of his plants average only 1.12 per cent for the *consimilis* variety, which is by far the most abundant one, but this is perhaps too low an average for all of the Utah shrub, since three samples of *consimilis* collected by ourselves near Stockton carried 1.31, 2.46, and 2.84 per cent of rubber, respectively. Whatever the exact average may be, it certainly is low and renders unnecessary the publication of detailed information as to distribution. The largest areas of shrub in Utah lie along the alkaline flats of Sevier Valley, Tooele Valley (and south to beyond Vernon), Tintic Valley, Rush Valley, Utah Valley, Juab Valley, and the valleys of the Price and Green rivers. By far the largest stand of shrub is along the Sevier River, where Professor Jones finds a strip about one-fourth mile wide by one hundred and fifteen miles long, extending from Panguitch north to Fayette, and he describes other large areas in that valley. In the valleys of northeastern Utah, such as the Uinta Basin, *Chrysothamnus* occurs only in small, isolated patches and is of no importance in preparing estimates. In northwestern Utah, the varieties present are those which carry but little if any rubber and there are no extensive areas even of these. To the southwest, however, there are some stands of *consimilis* that should be taken into account. There is one area of at least 20,000 acres along the line of the Salt Lake Railroad and farther south than any of those mentioned above. The shrubs are closely placed but quite small, the average weight being estimated at scarcely over one pound. A sample taken at Milford yielded 1.24 per cent of rubber. A single sample of *C. turbinatus* gathered on the plains near Lund analyzed 4.88 per cent of rubber. This species is too scarce to be of importance save as a starting point in breeding experiments.

According to Professor Jones, the average weight of Utah plants, after cutting off the twigs, is about fifteen pounds, but in order to be perfectly safe we have taken only ten pounds as the weight in making up our estimates.

From the data indicated above and taking 1.12 per cent as the average content, we estimate the total amount of rubber present in *Chrysothamnus* in Utah to be not less than 20,000,000 pounds.

g. DISTRICT 7—COLORADO

Our explorations in this state have been far from exhaustive, consisting only of one visit to the northwestern part, a north-and-south journey along the easterly base of the Rocky Mountains, a visit to the San Luis Valley, and notes and samples taken along the line of the Denver & Rio Grande Railroad. The only important area of *Chrysothamnus* that we have located is in the San Luis Valley of south central Colorado, where we estimate, from observation and from reports of reliable residents, that not less than 800,000 acres are fairly well covered with *Chrysothamnus* of the *pinifolius* variety. Over much of this area the plants stand about ten feet apart, that is, there are about four hundred and thirty-five plants to the acre. Since Grease-wood, or Chico (*Sarcobatus vermiculatus*) and other impurities occur in some portions of the valley, we have taken only one-half of this number as a basis for estimates. The plants are of medium size, the average weight after the removal of the non-rubber-bearing portions being perhaps five pounds. Two samples taken at Alamosa yielded 3.41 per cent and 1.11 per cent, respectively. A third, sent from near Center by Mr. Wm. O. Sauder, analyzed 3.59 per cent. This makes an average of 2.70 per cent of pure rubber. On this basis the total amount of rubber present in this one valley would be about 24,300,000 pounds. This is probably the largest single body of shrub in Colorado, if not in the whole West. Smaller but otherwise similar areas doubtless occur in some of the unvisited river valleys of the southwestern part of the state.[10] Along the Gunnison we found only small detached areas of Rabbit-brush and the same is true of the valley of the Yampa, in northwestern Colorado.

The most easterly stations at which we have found rubber-bearing shrubs lie along the east base of the Rocky Mountains from Fort Collins and Denver to Trinidad. Five samples of *graveolens* from these

[10] See p. 186, footnote.

places averaged less than 1 per cent of rubber and nowhere did we find other than small groups of the plants. A single sample of *frigidus* from Laramie, Wyoming, was found to carry 1.86 per cent of rubber. A sample of *pinifolius* from Salida yielded 4 per cent.

Our estimate of the total amount of rubber present in *Chrysothamnus* in Colorado is based entirely upon what was found in the San Luis Valley and is therefore, as indicated above, about 24,300,000 pounds.

h. ESTIMATES NOT INCLUDED IN THE ABOVE DISTRICTS

There are many districts in addition to those just enumerated that will need to be explored before a final statement as to the occurrence of rubber-bearing shrubs can be made. Large bodies of these plants might be found in any of the western states. The most promising of these, in addition to those already specifically mentioned, is perhaps Wyoming. It is well known that this state supports large areas of Rabbit-brush but aside from a few samples taken along the southern border we have made no study of its rubber possibilities. We have been told also of considerable areas in southern Montana, in Idaho, and in eastern Washington, but judging from the varieties there present the percentage of rubber in the plants is very low. In Nevada, which we have covered as well as any other state, there are still some promising unexplored fields. *Chrysothamnus* occurs in a number of species and varieties in New Mexico, according to good authority,[11] but we have scarcely considered that state. Professor A. O. Weese reports a great deal in the region around Albuquerque. Arizona is likewise a state of possibilities, but the areas of Rabbit-brush to be found there are probably quite limited in extent. These two southerly states should be carefully explored in case a search is made for new strains of high quality, since a considerable number of species and variants not yet examined are known to occur and the climatic conditions are such as would be expected to result in the formation of rubber.

i. CONCLUSIONS AS TO THE QUANTITY OF RUBBER OBTAINABLE

As previously noted, the explorations in search of rubber plants have not extended to all parts of the West, nor, indeed, has any single

[11] Vernon Bailey, Life Zones and Crop Zones of New Mexico. N. Am. Fauna, no. 35 (1913), pp. 28, 31, 37.
Wooton and Standley, Flora of New Mexico. Contrib. U. S. Nat. Herb., vol. 19 (1915), pp. 660–663.

state been thoroughly examined. The seven districts reported upon, however, furnish some indication of the total amount of rubber that might be obtained in case of need. The estimated amount already located by districts is as follows:

	Pounds
District 1—East Central California and adjacent Nevada	3,280,000
District 2—Mojave Desert, California	400,000
District 3—Northeastern California and adjacent Nevada and Oregon	1,000,000
District 4—West Central Nevada	7,680,000
District 5—Northern and Central Nevada	23,700,000
District 6—Utah	20,000,000
District 7—Colorado	24,300,000
	80,360,000

Taking this total of approximately 80,000,000 pounds as representing the probable amount of pure rubber present in the shrub located, it is believed that this estimate could be safely increased by 50 per cent by allowing for the presence of other areas within these districts, although we have not been able to visit them. After this has been done, we have still to account for several whole states as well as several fractions of states lying outside the seven districts noted above. We hesitate to venture a guess as to what these might yield but it seems probable that the total amount in all of the western states is not less than 300,000,000 pounds.

VIII. METHODS OF DETECTING THE PRESENCE OF RUBBER AND DETERMINING ITS AMOUNT

a. MICROSCOPICAL METHODS

Microscopical examinations of *Chrysothamnus* and related genera were at first undertaken as a short cut method of determining whether or not a given sample of shrub contained rubber. In addition we have attempted, with some success, to employ the microscopical method for estimating the relative amounts of rubber in the different samples. At the beginning of the investigations we were forced to rely upon this method almost entirely since facilities could not be secured for making ourselves the many chemical analyses which have since been carried through. Chemical analysis is, of course, the only method of making both the original determination and of obtaining an estimate of rubber present which is at once thoroughly dependable and really significant.

The microscopical method, in brief, consists in the cutting of cross sections of a mature portion of the sample and the making therefrom, after the action of suitable solvents, stains and mounting media, of a preparation in which the rubber, if present, may be seen under the microscope. As will be shown in the detailed description given below, the process of making such a preparation is simple and may be sufficiently well controlled to yield results that will be fairly uniform and reliable.

As in Guayule, the rubber in *Chrysothamnus* and *Haplopappus* is present within the individual cells of the plant, and is not a latex rubber. Like Guayule again it is found principally in the parenchymatous elements of the cortex; indeed it may occur in any undifferentiated elements lying without the cambium or, in other words, in what is often spoken of as the "soft" or "inner bark." It may also be noted here that rubber does not appear to be laid down during the first year of growth of a tissue and indeed, unless present in large amount, is not readily detected by the histological method in portions of the plant less than three or four years old. A section of a plant taken slightly above the soil line will exhibit tissues containing practically maximum quantities of rubber. In investigating new and untried species by the microscopical method it is wise to make sections from well down the root as well as at the soil line. This is indicated by our results on *Haplopappus* mentioned in the third part of this report. In certain species of that genus practically no rubber was found in sections of stem tissue, while quite appreciable amounts were shown in sections taken well down the main root. We have found in *Chrysothamnus* that maximum quantities are borne by the stem, although for a limited distance below the soil line the root may bear an almost equivalent amount.

In selecting and removing the material to be sectioned care must be exercised to retain the bark. This is often difficult, as the dry corky tissues readily split off, together with the living cortex, along the delicate cambium region, from the hard, woody cylinder. When the tissues are stripped off in this way it is useless to attempt the cutting of sections, since practically the entire rubber-bearing cortical area will be missing. It has been our practice to cut out the desired piece of mature woody tissue[12] and allow it to soak in water for twenty-four hours before sectioning. This treatment softens all the tissues and

[12] We have found that a coping saw can be very successfully employed to cut out the piece of stem to be sectioned.

renders more simple the handling of the important barky elements. The actual cross sections are made with a section knife or heavy-backed razor not hollow ground. The piece of material may be held in the fingers for cutting or in a so-called hand or well microtome. One of us has devised a modification of this type of microtome which was used in these investigations.[13] A sliding microtome has also been used. Successful sections can be cut only with an extremely sharp instrument and only a few sections can be cut before sharpening must be repeated. Smoothing the surface to be cut with a sharp pocket knife is desirable and saves for a time the finer edge of the sectioning razor. If interest centers entirely upon the question of the presence or absence of rubber, it is not essential that the sections cut be particularly thin nor that they be taken exactly at right angles to the long axis of the sample. In our work details of structure and other matters were often of special importance for which reason all sections were cut less than 50μ in thickness and were carefully oriented.

As noted by Lloyd[14] rubber when present in large amount is, after some practice, rather readily detected in fresh or unstained sections of non-latex rubber plants. When present in smaller quantities it is often indistinguishable from the protoplasmic matrix of the cell or is confused with accumulations of oil or resin in the tissues. According to our histological method oils and resins were dissolved out because of the relatively small amount of rubber usually present and especially as a preliminary to the use of a stain which was not definitive for rubber in the presence of these other substances. As a solvent, acetone was used exclusively, the sections being placed in a test tube half full of acetone and allowed to stand in a water bath at 60° C. for from fifteen to thirty minutes. For staining the sections we at first tried alkanin,[15] but Sudan III was early found to be more satisfactory and was therefore employed in the great majority of the histological examinations. Our Sudan III was made up with glycerine according to Stevens' formula.[16] This stain imparts a brilliant scarlet color to fats, resins and rubbers as they occur in the cell. By the previous acetone extraction fats and resins had been dissolved from the cell contents but rubber was left practically unaffected and if present took up the stain. The stain was allowed to act for eighteen hours, after which the

[13] Goodspeed, T. H., Modification of hand microtome. Bot. Gaz., vol. 66 (1918), p. 534.

[14] Lloyd, F. E., Guayule. Carnegie Inst. Publ. no. 139 (1911), p. 176.

[15] Cf. Stevens, W. C., Plant anatomy, 3d ed. (1916), p. 293.

[16] *L.c.*, p. 337.

excess was washed from the sections with 50 per cent alcohol. The sections were then mounted in glycerine and in some cases were ringed.

Some search has been made for a staining method which would be strictly definitive for rubber and which would result in imparting such a characteristic color to the rubber cell-inclusions as would serve to distinguish them definitely from all other inclusions. The desirability of securing such a staining method is seen in the fact noted above, that alkanin and Sudan III are in histological practice used to indicate the presence of resins and fats, respectively, and thus their ability to stain rubber in the cell is in a sense more or less fortuitous. The fact that alkalin is a specific stain for resins might suggest a corresponding staining reaction in the case of rubber. As far as Sudan III is concerned, however, we are employing a stain used in animal histology to give definition to globules of fat occurring in the cell. Without going into the question of the chemistry and differential staining of the fats, fatty acids, and lipoids, it may be noted that the staining of fat globules by Sudan III is taken to indicate that this stain is soluble in the contents of the fat globule whereas it is not soluble in the other constituents of the cell which, therefore, remain unstained. It is somewhat difficult with this explanation of the characteristic staining reaction of Sudan III in mind, to understand its action in the case of rubber. This matter is mentioned simply to call attention to the possible theoretical interest attached to the problem of the staining of rubber inclusions in the cell.

We have, further, been interested in this matter because cell inclusions have been consistently found in chlorophyllous tissue of both stems and leaves which, with Sudan III, stained as rubber, but which were difficult to differentiate with this stain from the residue of the protoplast with its included chloroplasts, which does not in such tissue entirely disappear after acetone extraction and which stains to some extent with Sudan III. In this connection it should be stated that in other tissues also it is difficult to distinguish between the protoplasmic matrices of the cells which may be stained with Sudan III and the rubber inclusions which may or may not be present. Thus in the tables which follow it is in some cases possible that the plants which on the basis of "microscopical examination" are stated to contain "traces" of rubber may have shown only stained cell inclusions which could not positively be identified as rubber.

We have made some preliminary investigation of the effects of a variety of stains. A number of staining combinations were attempted,

especially in the case of sections involving chlorophyllous tissue, to stain the protoplasmic matrix of the cell and follow with Sudan III. It appears that a heavy staining with Orange G. followed by Sudan III may be a useful combination in this connection. Of a number of stains ordinarily employed for the differentiation of the elements of woody tissue one at least gave some indication of being of interest. Sections were placed in Delafield's haematoxylin for twelve hours, partially destained and placed over night in Sudan III. In the resulting preparation the rubber inclusions were stained scarlet by Sudan III while in the center of each was a single spot of dark purple indicating, apparently, that each rubber globule contains a protoplasmic "nucleus" around which it is built up. Results of this sort indicate a field for further investigation.

It occurred to us, also, that vulcanization of the rubber *in situ* might be possible, and thus giving specific differentiation under the microscope to rubber inclusions in the cell. After suitable dehydration, sections were placed in the cold in sulfur chloride (in carbon tetracholoride) or were allowed to stand in the fumes of such a solution. The results of a number of preliminary experiments indicated that vulcanization of the rubber inclusions in the cells was possible.

The following outline of the process of making preparations of rubber-containing tissue described in some detail above may be of assistance to those who may desire to make histological examinations for a similar purpose. Attention must be called to the fact that nothing original is claimed for this process, nor will it necessarily prove successful in all its details for other species.

It is assumed that a woody plant is under investigation and that sections have been cut from a sample of mature tissue.

(1) Sections from water to 95 per cent alcohol; 5 minutes.

(2) Boiling acetone; 15 to 30 minutes.

(3) Sudan III; 18 hours.

(4) Wash off excess of stain in 50 per cent alcohol; as rapidly as possible.

(5) Mount in pure glycerine.

A preparation made in this manner from material cut from a relatively high percentage plant of *Chrysothamnus nauseosus* will show cell inclusions of rubber stained a brilliant scarlet. At a magnification of 150 diameters the parenchymatous elements of the cortex and especially the broad wedge-shaped cortical extensions of the primary

rays will appear to be solidly filled with stainable material. In the younger corky layers of the inner bark stainable cell inclusions will probably be numerous. Nearer the periphery a tissue which is often intensely stained will usually be found, with greater magnification, to consist largely of much crushed bark cells the suberized walls of which take up the stain readily. Within the cell the rubber occurs in globular form or in a more or less diffused state filling the entire cell cavity. The globules may be large, one or two to a cell, or small and numerous in each cell (cf. plate 18, figs. 4 and 5). Only this brief description will be made here of the appearance of a typical preparation made according to the process detailed above. The subject of the occurrence of rubber in the plant and in the cell is treated of in some detail elsewhere (cf. p. 234).

As mentioned in an earlier paragraph, we have attempted with some success to use the microscopical method for estimating the relative amounts of rubber in the various samples examined. A purely arbitrary scale of values was adopted and relative rubber content determined in each case by comparison with other preparations selected as representing high, low, and medium rubber content. For such comparisons a comparison-ocular was found to be useful. Uniformity in the quality and quantity of the illumination is quite important and artificial light was therefore used throughout. As soon as it became possible to obtain large numbers of chemical analyses the histological method of estimation became largely superfluous. However, in almost all cases it was resorted to prior to the chemical analysis and a rough estimate made. Often when the rubber content of a sample appeared to be quite low no chemical analysis was made, and a considerable amount of time and labor was thus saved. Throughout the investigation we continued to examine microscopically numbers of samples of doubtfully valuable species which were suspected by others of containing rubber or which were collected by ourselves in order that no possible source of rubber accessible to us should be overlooked.

We have found the microscopical method invaluable in many phases of this investigation. The question as to the place and time of the origin of rubber in the plant can only be answered by employing this method. Furthermore, supplemented by chemical analysis it gives important evidence concerning the parts of the plant which carry rubber and their richness relative to age and location. Ultimately the season and method of harvesting such a rubber crop will be determined largely on the basis of information so derived.

b. CHEMICAL ANALYSIS

The original chemical analysis of *Chrysothamnus* was made in October, 1905, by Professor G. E. Colby of the California Experiment Station. At the start of our investigations in 1917 a few analyses were very kindly made for us by Professor P. L. Hibbard of the same station. The great majority of the analyses listed in the various tables which follow were made under the direction of the junior author, in whose laboratory the necessary grinding and extraction apparatus was set up.

The particular method of chemical analysis which we have almost exclusively employed consists in the thorough extraction of a finely ground sample of material, first with acetone and second with benzene. The acetone extract is taken to contain approximately all resins, fats, and similar bodies; the benzene extract to contain the rubber. A detailed schedule of the whole process is given below for the convenience and assistance of those who may care to make use of this method or some improvement upon it. It is to be understood that the periods of extraction as well as the length of the periods of drying to constant weight were definitely determined after a large number of preliminary efforts. The few early extractions were made with one of the numerous modifications of the Soxhlet apparatus, while for the great majority the Bailey-Walker extractor was employed. The acetone extraction was made over the water-bath, the benzene extraction on electric hot plates. The method may be summarized as follows:

(1) Five-gram sample extracted 3 hours, boiling acetone.

(2) Acetone flask dried 8 hours, cooled in desiccator and weighed.

(3) Material in extraction thimble or siphon tube dried, placed in a second flask, and subjected to action of boiling benzene for 3 hours.

(4) Flask containing benzene extract dried 4 hours, cooled in desiccator, and weighed.

Two layers of filter paper were placed at the bottom of the siphon tube, as well as a plug of cotton. So complete a protection was this arrangement against the coming over of particles of the sample that filtration of the solution at the completion of the extraction was not necessary. Similarly, a plug of cotton placed upon the top of the material in the siphon tube obviated any danger of an overflowing of

the finely divided sample, especially as the bottom of the condenser pressed down on this cotton plug during the course of the extraction.

In almost all cases the first of the acetone-soluble substances extracted were strongly colored and turned the solvent a dark greenish brown as soon as the extraction commenced. Thereafter the liquid passing through the siphon tube was practically colorless. The benzene extract was in practically all cases entirely without color. The acetone extract after drying was very dark brown in color and strongly odorous. The benzene extract when dry was on the other hand colored light brown or yellowish, was almost entirely odorless, and was distinctly rubber-like in consistency.

There are, of course, a variety of other methods of analysis which might possibly have successfully replaced the one which we have employed throughout. For the sake of comparison we made trial of another method, according to which the sample is first extracted thoroughly with gasoline, then treated with strong sodium hydroxide, then filtered, and the residue, finally, extracted with carbon tetrachloride. This method is far more time-consuming than the one which we have used and appeared to offer no real advantages as compared with it. In the extraction of Guayule shrub on a large scale gasoline is sometimes used as the solvent and acetone as a precipitant. The recovery of these reagents used in large quantity in such a process is a complicated problem but it can be accomplished with very slight losses. Moisture determinations were made in most cases.

The following table indicates something as to the relative accuracy of our chemical analyses. Duplicate or triplicate analyses were often run in cases where comparisons were to be made with analyses of other parts of the same plant or with equivalent portions of a given individual collected on various different dates. The figures given are selected as being representative. They indicate a relative degree of accuracy for our analyses, sufficient at least to give an estimate of the average amount of rubber contained in the various species with which we have been concerned.

TABLE 1.—THE RESULTS OF A NUMBER OF DUPLICATE ANALYSES

	Species or variety	Place of Collection	Date of Collection 1918	Acetone Extract Per cent.	Benzene Extract Per cent.
157	Haplopappus ericoides	San Francisco, Calif.	July 27	6.67	2.10
		San Francisco, Calif.	July 27	4.99	1.89
203	C. n. gnaphalodes*	Kearsarge, Inyo Co., Calif.	Jan. 28	2.81	1.45
		Kearsarge, Inyo Co., Calif.	Jan. 28	2.56	1.46
206	Haplopappus nanus	Near Benton, Calif.	Feb. 19	9.57	6.72
		Near Benton, Calif.	Feb. 19	10.41	6.88
220	C. n. consimilis	Near Wabuska, Nev.	Feb. 27	3.69	2.75
		Near Wabuska, Nev.	Feb. 27	3.62	2.95
240	C. n. speciosus	Near Weed, Calif.	June 6	2.90	1.48
		Near Weed, Calif.	June 6	2.43	1.52
255	C. n. speciosus	East of Hammett, Idaho	June 22	4.59	2.67
		East of Hammett, Idaho	June 22	4.65	2.56
		East of Hammett, Idaho	June 22	5.19	2.49
		East of Hammett, Idaho	June 22	4.69	2.70
		East of Hammett, Idaho	June 22	4.16	2.52
		East of Hammett, Idaho	June 22	4.06	2.60
		East of Hammett, Idaho	June 22	4.20	2.58
257	C. n. consimilis	Shoshone Falls, Idaho	June 23	3.90	2.63
		Shoshone Falls, Idaho	June 23	3.51	2.56
290	C. n. pinifolius	Alamosa, Colo.	Aug. 31	4.27	3.41
		Alamosa, Colo.	Aug. 31	4.70	3.40
		Alamosa, Colo.	Aug. 31	4.23	3.59

* In this and following tables the initial letters C. n. are used to indicate *Chrysothamnus nauseosus.*

The reduction by maceration and grinding of woody plants for detailed chemical analysis of the contents of their tissues is at best attended with some difficulty. The difficulties were somewhat magnified in the material with which we worked, since the wood of most species of *Chrysothamnus* is quite hard and since, also, it was necessary in most cases to grind green shrub.

Each plant to be analyzed was trimmed with care. Since it seemed clear that for all practical purposes the older portions of the main stem contained maximum quantities of rubber, all the younger shoots and most of the root was eliminated previous to grinding. Figure 4 shows portions of a representative plant of *Chrysothamnus nauseosus* var. *viridulus* trimmed in this way and ready for grinding.

Usually such large plants were cut up into a number of equivalent portions, alternate pieces being used for grinding. In some cases where the plants were unusually large the trimmed mass was split longitudinally into portions as nearly equivalent as possible. In this connection may be mentioned the difficulty of performing this operation successfully. It is evident that the including of "bark" belonging

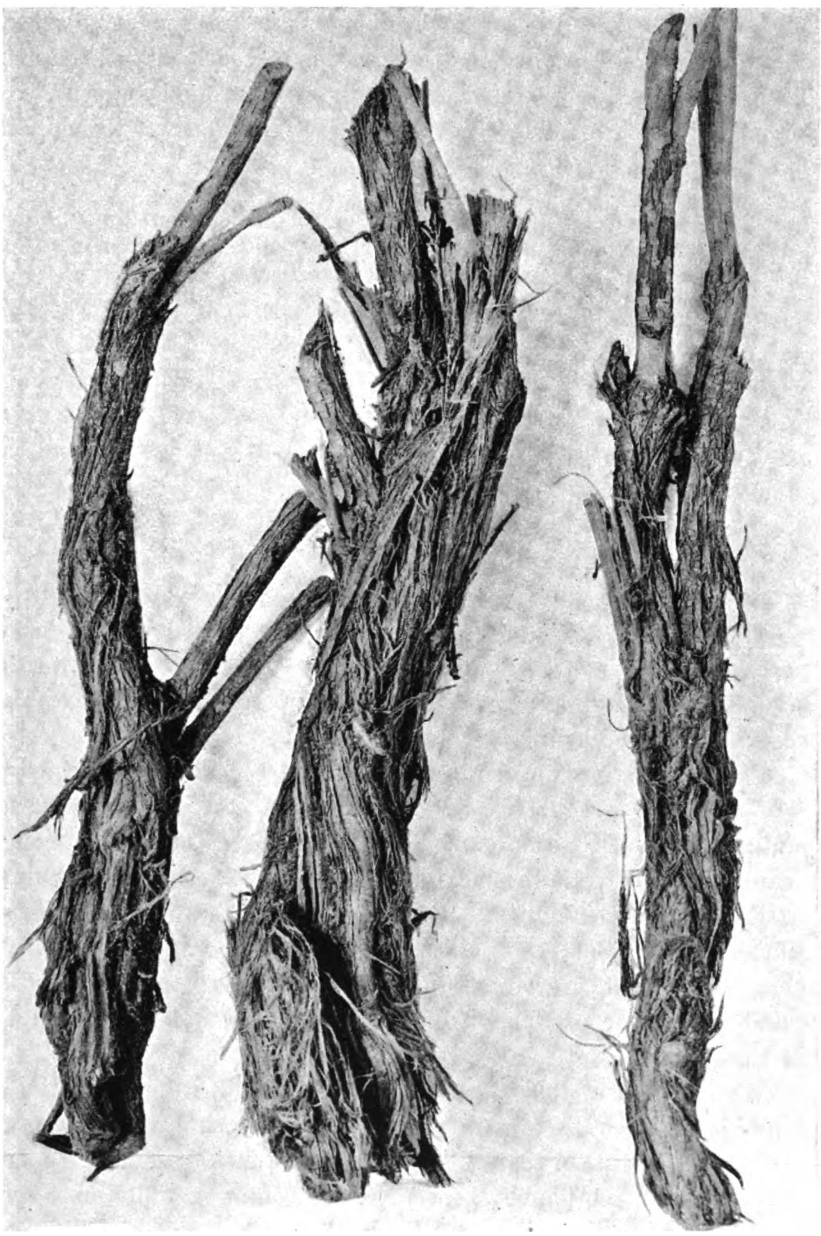

Fig. 4. Portions of a representative plant of *Chrysothamnus nauseosus* var. *viridulus* trimmed and ready for grinding.

to one portion along with the portion to be ground will decidedly affect the rubber content of the ground sample since the greater part of the rubber is contained in the extra-cambial elements of the stem. To test this matter we ran a few analyses of ground material from both portions of a number of plants. The results are given in the following table.

Table 2.—Variation in Rubber Content Due to Unequal Separation, Shown by Analyses of Both Halves of Large Plants which had been Split Longitudinally

	Species	Place of Collection	Date of Collection 1918	Acetone Extract Per cent.	Benzene Extract Per cent.
455	C. n. consimilis	Adobe Valley, Calif.	Sept. 19	3.70	2.55
		Adobe Valley, Calif.	Sept. 19	3.75	2.44*
		Adobe Valley, Calif.	Sept. 19	3.21	2.81
457	C. n. consimilis	Gaspipe, Calif.	Sept. 19	3.66	1.95
		Gaspipe, Calif.	Sept. 19	2.97	2.07
467	C. n. viridulus	North of Mono Lake, Calif.	Sept. 22	3.71	1.74
		North of Mono Lake, Calif.	Sept. 22	2.28	2.47

* Duplicate analysis.

These figures indicate that care must be exercised in splitting off portions of a plant for grinding and analysis. As noted above it has been almost uniformly our practice to cut up larger plants into transverse sections and grind alternate pieces.

For the first rough crushing or grinding a small power driven feed mill proved satisfactory. The material was run through this mill a number of times, the grinding plates being continually brought nearer together until the maximum degree of fineness was attained. At this stage practically all the material could be passed through a 10-mesh sieve. For the final grinding a hand-operated No. 0 Enterprise coffee mill proved successful. The final result of this last grinding was the production of material that would pass through a 24-mesh sieve.

We have attempted with some success to substitute the action of a pebble mill for the greater part of the final grinding.[17] Since the rubber is held within the walls of the individual cells and since, even when put into solution by benzene, these confining walls must serve to hinder outward diffusion of the rubber to some extent, it seemed

[17] A modification of a small Abbe pebble mill (''single specimen mill'') was used. Mention might here be made of the fact that there are on the market a number of power driven grinding machines which would undoubtedly perform an initial reduction to 10-mesh much more rapidly and evenly than the apparatus described above.

clear that previous to extraction the finest possible subdivision of the plant material was desirable. Preliminary tests indicated that after prolonged grinding in the pebble mill a greater reduction in size of particles was attained than by our usual final grinding in the coffee mill. Examination of the pebbles at the end of their action showed particles of rubber as well as woody and fibrous tissue adhering to their surfaces. We therefore made a number of analyses to determine. if possible, just what proportion of the rubber was left behind on the pebbles after pebble mill grinding. The following table indicates the relation in each case between the amount of rubber extracted from a sample of the ground material as it came out of the pebble mill and the amount extracted from another portion of the same rough ground material which had been reduced in the coffee mill. Attention should be called to the fact that no rubber was found to adhere to the metal grinding plates of the feed mill or coffee mill and that both were taken apart and brushed out after each grinding, the material remaining in the mills being added to the ground substance which had gone through them. In a few cases material was ground in a pebble mill operated in the Food and Drug Laboratory of the University of California. This mill was larger than ours and the product was somewhat more finely divided than the product of our pebble mill.

Table 3.—Influence Upon the Results of Analysis of Final Grinding in a Coffee Mill and in a Pebble Mill

	Species	Acetone Extract Per cent.	Benzene Extract Per cent.	Remarks
87	C. n. gnaphalodes	2.78	0.59	Coffee mill.
		3.07	0.46	Pebble mill. 4 hours.
133	C. n. viridulus	4.12	3.64	Coffee mill.
		4.60	4.06	Pebble mill. 4 hours.
134	C. n. viridulus	3.73	2.18	Coffee mill.
		3.93	2.14	Pebble mill. 4 hours.
135	C. n. viridulus	4.57	1.30	Coffee mill.
		3.69	1.29	Pebble mill. 6 hours.
		4.07	1.22	Pebble mill (Food & Drug Lab.)
140	C. n. consimilis	4.76	3.86	Coffee mill.
		5.50	3.89	Pebble mill. 4 hours.
144	C. n. consimilis	3.75	0.81	Coffee mill.
		3.74	0.79	Pebble mill. 4 hours.
146	C. n. consimilis	3.69	1.74	Coffee mill.
		3.54	1.54	Pebble mill. 4 hours.

TABLE 3.—(CONTINUED)

	Species	Acetone Extract Per cent.	Benzene Extract Per cent.	Remarks
149	Haplopappus ericoides	9.17	3.92	Coffee mill.
		7.88	2.48	Pebble mill. 4 hours.
		7.47	3.11	Coffee mill.
		5.53	2.50	Pebble mill. 4 hours.
215	C. n. gnaphalodes	4.29	2.57	Coffee mill.
		4.29	1.92	Pebble mill. 4 hours.
227	C. n. consimilis	3.98	2.14	Coffee mill.
		4.30	2.12	Pebble mill. 4 hours.
229	C. n. speciosus	3.55	2.49	Coffee mill.
		4.83	2.37	Pebble mill. 6 hours.
		4.72	2.07	Pebble mill (Food & Drug Lab.)

Although, as in all such cases, a far larger number of analyses is necessary to give entirely reliable evidence it appears from the figures given above that the product of the pebble mill, irrespective of the fact that some rubber is kept behind on the pebbles, yields approximately as large an amount of rubber as does the product of the coffee mill. The results given in the following table leave no room for doubt that rubber does adhere to the pebbles.

TABLE 4.—EVIDENCE THAT RUBBER ADHERES TO THE PEBBLES WHEN MATERIAL IS GROUND IN A PEBBLE MILL

	Species	Acetone Extract Per cent.	Benzene Extract Per cent.	Remarks
206	Haplopappus nanus	9.57	6.72	Coffee mill.
		8.71	6.22	Pebble mill. 4 hours.
		8.88	8.51	Pebble mill. 4 hours. Pebbles washed in benzene and solution filtered. Residue (2gm.) added to ground material (3gm.) and whole extracted with filtrate.

In view of these results the conclusion seems inevitable that the degree of fineness of the ground material is an important factor in the extraction of rubber from non-latex rubber-bearing plants according to our method of chemical analysis. Apparently the added fineness of the product of the pebble mill facilitates the thorough extraction of the rubber to such an extent that the amount of rubber added by this more nearly complete extraction compensates for the amount retained upon the pebbles. In other words if over 2 per cent of rubber is held on the pebbles, as is indicated by the results given in table 4, one might expect that the benzene extract from pebble mill material would be approximately 2 per cent less than that from coffee

mill material. In fact, however, these two analyses were in most cases approximately the same and this result is assumed to depend upon the fact that the finer division of the product of the pebble mill allows the extraction of 2 per cent more rubber than was possible in the case of the coarser product of the coffee mill.

With these facts in mind we decided to make the final grinding of all our samples in the coffee mill since the matter of removing the rubber adhering to the pebbles of the pebble mill is somewhat difficult and time-consuming. This was done as a matter of practicability notwithstanding the knowledge that the results would be too low to express the actual percentages present. The discrepancy, however, cannot be anywhere near the 2 per cent mentioned since that referred to a plant in which the rubber content is much higher than the average, and one moreover in which the very resinous material adhered to the pebbles more persistently than in most cases. It is believed that the amount of rubber remaining in samples of *Chrysothamnus nauseosus* after grinding in a coffee mill and extracting by our method seldom if ever approaches 1 per cent of the original sample.

In a preliminary way, at least, we have obtained evidence as to the effect of storage of the ground material upon rubber content. At the start of our investigations it was assumed that if for any reason a plant was not analyzed almost immediately after collection a deterioration in content and quality of the contained rubber would soon render the result of its analysis of doubtful value. Undoubtedly the exposure of shrub to drying and weathering out of doors will bring about such deterioration in the course of time (cf. Lloyd, *l.c.*, p. 10). As has been noted above (p. 220) it is difficult so to divide a plant for analysis that the halves or apparently equivalent portions will give closely corresponding analyses. For this reason we did not attempt, in seeking evidence as to the influence of storage upon rubber content, to analyze a portion of a plant and after subsequent storage for some months analyze an apparently equivalent portion represented by the remainder of the same plant. Rather the residue, after the first analysis, of the ground material of a plant was stored in a stoppered bottle and analyzed after a time. We have assumed that the amount of deterioration in such a finely ground sample after storage approximates that which might be expected to occur within the tissues of an entire plant after a corresponding period of time. The table which follows details the results of a number of analyses of ground material shortly after the original dates of collection and after periods of storage varying from five to ten months.

TABLE 5.—EFFECT OF STORAGE OF GROUND MATERIAL UPON RESULTS OF CHEMICAL ANALYSES

Collection Number	Species	Place of Collection	Date of Collection	Date of Analysis	Acetone Extract Per cent.	Benzene Extract Per cent.	Remarks
206	Haplopappus nanus	Near Benton, Calif.	Feb. 19, 1918	June 18, 1918	9.57	6.72	Stem
				Jan. 25, 1919	8.37	6.61	Stem, after 6 months
				June 18, 1918	5.96	5.29	Root
				June 18, 1918	6.02	6.40	Root, dup. analysis
				Jan. 25, 1919	6.53	6.42	Root, after 6 months
				Jan. 25, 1919	6.46	6.53	Root, dup. analysis
240	C. n. speciosus	Near Weed, Oregon	June 6, 1918	June 28, 1918	3.06	1.50	Stem
				April 5, 1919	2.90	1.48	Stem, after 10 months
				April 5, 1919	2.43	1.52	Stem, dup. analysis
255	C. n. speciosus	East of Hammett, Idaho	June 22, 1918	July 15, 1918	4.59	2.67	Stem
				July 15, 1918	4.65	2.56	Stem, dup. analysis
				July 15, 1918	5.19	2.49	Stem, another dup. an'is
				July 28, 1918	4.69	2.70	Stem, another dup. an'is
				Jan. 26, 1919	4.16	2.52	Stem, after 6 months
				Jan. 26, 1919	4.06	2.60	Stem, dup. analysis
				Jan. 26, 1919	4.20	2.58	Stem, another dup. an'is
256	Haplopappus nanus	Shoshone Falls, Idaho	June 23, 1918	July 10, 1918	5.86	4.61	Stem
				July 18, 1918	5.90	4.66	Stem, dup. analysis
				Jan. 26, 1919	4.94	4.54	Stem, after 6 months
				Jan. 26, 1919	5.33	4.46	Stem, dup. analysis
257	C. n. consimilis	Shoshone Falls, Idaho	June 23, 1918	July 22, 1918	4.32	2.70	Stem
				April 5, 1919	3.90	2.63	Stem, after 9 months
				April 5, 1919	3.51	2.56	Stem, dup. analysis
279	C. n. graveolens	Trinidad, Colo.	Aug. 11, 1918	Sept. 8, 1918	2.65	1.03	Stem
				Sept. 8, 1918	2.44	0.94	Stem, dup. analysis
				April 14, 1919	2.44	0.91	Stem, after 7 months
				April 14, 1919	2.16	0.93	Stem, dup. analysis
416	Haplopappus nanus	Caliente, Nev.	Sept. 6, 1918	Sept. 24, 1918	4.49	8.42	Stem
				Jan. 25, 1919	3.59	8.23	Stem, after 5 months
				Jan. 25, 1919	4.12	8.41	Stem, dup. analysis

It seems clear from the above figures that there is little to be feared in the way of loss of rubber by the storage for some months of the ground material of such rubber bearing plants as those which we have investigated. It is assumed that a similar statement can be made for plants in their original condition when stored in the laboratory or mill under more or less uniform conditions of temperature and moisture.

Attention might be called to the fact that in table 5 it appears that the content of acetone-soluble substances in general shows a somewhat greater diminution in amount following storage than does the rubber content. Further experiments along this general line are planned since evidence may, seemingly, be obtained regarding the relation between resins as well as other acetone soluble substances and rubber. Indeed other analyses of stored material, not so well controlled and therefore not included in table 5, indicate that accompanying the loss of resins, etc., there is an actual increase in rubber after storage.

It had been our original intention to include in the various tables which follow the date of analysis as well as the date of collection. Since the period elapsing between these two dates seems to have little or no influence upon the rubber content of a plant the former date was eliminated. It should be said, however, that every effort was made to analyze the various plants as soon as possible after they were brought into the laboratory. In the majority of cases less than a month or six weeks intervened between collection and analysis.

IX. RESULTS OF THE CHEMICAL ANALYSES AND MICROSCOPICAL EXAMINATIONS; TABULATION OF PERCENTAGE OF RUBBER IN EACH VARIETY

The methods employed in making the chemical analyses and microscopical examinations have been detailed elsewhere (cf. p. 210). The following tables give the results of such analyses and examinations as were made on individual plants of a number of varieties of *C. nauseosus*. As in previous tables the collection number is included for the sake of completeness and for future reference. The date of analysis is not given because of considerations mentioned above. The "X" following certain of the percentages indicates that they are not based upon dry weight. In all other cases moisture determinations were made, and the figures are based upon dry weight.

The terms used in describing the amount of rubber determined by microscopical examination are only relative and are derived from a more elaborate classification used during the course of the investigations.

In the reports on the chemical analyses, the first column, or "acetone extract" is taken to represent the percentage of resins, fats, waxes, etc., in the sample while the second column indicates the per centage of pure rubber, or Chrysil. As indicated on page 223, the figures in this second column are probably too low by a fraction of 1 per cent in each case owing to the difficulty of obtaining the proper degree of fineness in grinding the samples.

A summary of these tables is given on page 244.

We are under great obligation to Miss Mildred Crane who undertook the carrying through of the majority of the chemical analyses and assisted during the entire investigation in a variety of ways.

TABLE 6.—RESULTS OF CHEMICAL ANALYSES AND MICROSCOPICAL EXAMINATIONS OF INDIVIDUAL PLANTS OF TWELVE VARIETIES OF *Chrysothamnus nauseosus*

Chrysothamnus nauseosus (*sensu strictu*)

MICROSCOPICAL EXAMINATIONS

	Place of Collection	Date of Collection	Estimated Amount
251	Near Harney, Ore.	June 19, 1918	Nothing
463	Mono Lake, Calif.	Sept. 20, 1918	Traces

Chrysothamnus nauseosus var. **consimilis**

CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
16	Deeth, Nev.	June 17, 1917	3.10	2.30
139	Golconda, Nev.	Mar. 4, 1918	4.72	2.21
140	Golconda, Nev.	Mar. 4, 1918	4.76	3.86
141	Golconda, Nev.	Mar. 4, 1918	5.12	3.71
142	Golconda, Nev.	Mar. 4, 1918	4.70	2.27
143	Golconda, Nev.	Mar. 4, 1918	3.85	1.07
144	Golconda, Nev.	Mar. 4, 1918	3.75	0.81
145	Golconda, Nev.	Mar. 4, 1918	3.59	2.12
146	Golconda, Nev.	Mar. 4, 1918	3.69	1.74
208	Near Blair Junction, Nev.	Feb. 24, 1918	5.58	2.90
210	Near Millers, Nev.	Feb. 24, 1918	3.67	4.17
214	Schurz, Nev.	Feb. 26, 1918	4.32	0.99
216	Schurz, Nev.	Feb. 26, 1918	3.62	0.65
217	Walker River, Nev.	Feb. 27, 1918	4.77	1.27
218	Walker River, Nev.	Feb. 27, 1918	3.79	2.17
219	Walker River, Nev.	Feb. 27, 1918	5.06	1.03
220	Near Wabuska, Nev.	Feb. 27, 1918	3.69	2.75
227	Karlo, Modoc Co., Calif.	Mar. 7, 1918	3.98	2.14
231	Karlo, Modoc Co., Calif.	Mar. 8, 1918	4.26	2.23
232	Honey Lake Valley, Calif.	Mar. 9, 1918	5.17	2.43
241	Near Weed, Calif.	June 6, 1918	3.25	1.02
250	Near Burns, Ore.	June 19, 1918	2.55	0.89
253	Near Ontario, Ore.	June 20, 1918	3.57	3.14
254	Southeast of Mt. Horne, Idaho	June 20, 1918	2.50	0.46x
257	Shoshone Falls, Idaho	June 23, 1918	3.90	2.63
402	Stockton Lake, Utah	Sept. 3, 1918	2.28	2.46
403	Stockton Lake, Utah	Sept. 3, 1918	3.14	1.31
404	Stockton, Utah	Sept. 3, 1918	3.91	2.84
408	Milford, Utah	Sept. 4, 1918	4.64	1.25
430	Goldfield, Nev.	Sept. 9, 1918	1.65	1.69
455	Adobe Valley, Calif.	Sept. 19, 1918	3.70	2.55
456	Adobe Valley, Calif.	Sept. 19, 1918	4.77	2.84
457	Gaspipe, Calif.	Sept. 19, 1918	3.66	1.95
472	Near Mountain House, Nev.	Sept. 22, 1918	3.44	1.26
473	Carson, Nev.	Sept. 23, 1918	2.08	2.85
474	Carson, Nev.	Sept. 23, 1918	2.70	2.30
475	North side of Carson River, Nev.	Sept. 23, 1918	4.62	2.42
476	South side of Carson River, Nev.	Sept. 23, 1918	3.14	0.59
477	Southeast of Gardnerville, Nev.	Sept. 23, 1918	3.75	0.83
478	South of Carson, Nev.	Sept. 23, 1918	2.82	3.54
479	East of Carson, Nev.	Sept. 23, 1918	3.12	3.79
480	Near Dayton, Nev.	Sept. 23, 1918	3.92	1.97
507	Stockton Lake, Utah	Sept. 25, 1918	1.74	0.20
514	Cedar Valley, Utah	Oct. 12, 1918	2.43	0.15
519	Muskrat Springs, Utah	Oct. 24, 1918	2.73	0.48
520	Near Josepha, Utah	Oct. 24, 1918	3.16	1.23
522	Tooele Valley, Utah	Oct. 24, 1918	3.47	0.62
523	Vernon, Utah	Oct. 24, 1918	2.64	0.67x
524	Utah Lake, Utah	Oct. 30, 1918	2.69	1.63
527	Sanpete Valley, Utah	Nov. 12, 1918	3.00	1.25x

CHEMICAL ANALYSES (CONTINUED)

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
527a	Sanpete Valley, Utah	Nov. 12, 1918	2.46	0.39x
528	Redmond, Utah	Nov. 12, 1918	3.10	3.48x
528a	Redmond, Utah	Nov. 12, 1918	2.33	1.77x
530	Circle City, Utah	Nov. 12, 1918	3.04	1.26x
532	Panguitch, Utah	Nov. 12, 1918	2.90	2.00x
533	Mona, Utah	Nov. 12, 1918	2.52	0.82x
534	Goshen, Utah	Nov. 18, 1918	2.80	0.81x
600	Golconda, Nev.	Dec. 23, 1918	3.30	1.51
602	Watts, Nev.	Dec. 24, 1918	3.27	1.58
603	Reese River Valley, Nev.	Dec. 25, 1918	3.72	1.07
604	Battle Mountain, Nev.	Dec. 28, 1918	3.41	2.98
605	Near Ely, Nev.	Dec. 30, 1918	2.98	0.54
606	Near Ely, Nev.	Dec. 30, 1918	3.64	1.84
607	Near McGill, Nev.	Dec. 31, 1918	3.80	1.15
608	Near McGill, Nev.	Dec. 31, 1918	3.04	1.04
609	Shafter, Nev.	Jan. 1, 1919	5.06	3.04
610	Shafter, Nev.	Jan. 1, 1919	4.15	1.21
611	Lamoille, Nev.	Jan. 2, 1919	3.13	1.08
613	Near Elko, Nev.	Jan. 2, 1919	3.66	0.43
614	North fork of Humboldt River, Nev.	Jan. 3, 1919	3.42	1.07
615	North fork of Humboldt River, Nev.	Jan. 3, 1919	3.36	0.93
650	Near Macdoel, Siskiyou Co., Calif.	Dec. 25, 1918	3.35	1.57
651	Blitzen Valley, Ore.	Dec. 27, 1918	2.91	0.78
652	Catlow Valley, Ore.	Dec. 29, 1918	3.44	2.06
653	Warner Valley, Ore.	Dec. 29, 1918	4.00	1.68
654	Warner Valley, Ore.	Dec. 29, 1918	3.25	0.84
655	Warner Valley, Ore.	Dec. 29, 1918	2.95	1.43
656	Quinn River Valley, Nev.	Jan. 3, 1919	4.79	3.36
657	Quinn River Valley, Nev.	Jan. 3, 1919	3.64	2.83
659	Near Gerlach, Nev.	Jan. 3, 1919	4.23	4.71
660	Near Gerlach, Nev.	Jan. 3, 1919	3.08	6.57

MICROSCOPICAL EXAMINATIONS

	Place of Collection	Date of Collection	Estimated Amount
11	Pyramid Lake Road, Nev.	June 14, 1917	Fair
26	Goldfield, Nev.	Aug. 10, 1917	Fair
32	Pyramid Lake Road, Nev.	Aug. 16, 1917	Fair
159	Near Magdalena, New Mex.	July 22, 1918	Poor
233	Honey Lake Valley, Calif.	Mar. 9, 1918	Fair
252	Near Westfall, Ore.	June 20, 1918	Traces
253	Southeast of Burley, Idaho	June 24, 1918	Traces
260	Southeast of Albion, Idaho	June 24, 1918	Traces
261	Southeast of Snowville, Utah	June 25, 1918	Poor
263	Near Duchesne, Utah	June 30, 1918	Traces
417	Caliente, Nev.	Sept. 6, 1918	Traces
502	Grantsville, Utah	Sept. 25, 1918	Traces
505	Stockton Lake, Utah	Sept. 25, 1918	Nothing
506	Stockton Lake, Utah	Sept. 25, 1918	Traces
513	Cedar Valley, Utah	Oct. 12, 1918	Poor
521	Near Josepha, Utah	Oct. 24, 1918	Poor
525	Near Jericho, Utah	Oct. 30, 1918	Traces
526	Doremus, Utah	Oct. 30, 1918	Poor

Chrysothamnus nauseosus var. frigidus

CHEMICAL ANALYSIS

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
271	Laramie, Wyoming	July 7, 1918	16.60	1.86

MICROSCOPICAL EXAMINATION

	Place of Collection	Date of Collection	Estimated Amount
262	Near Rock Hill, Utah	June 30, 1918	Traces

Chrysothamnus nauseosus var. gnaphalodes

CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
48	West of Lancaster, Calif.	Oct. 27, 1917	3.10	1.90
72	Benton, Calif.	Nov. 5, 1917	4.10	3.60^x
87	West of Lancaster, Calif.	Jan. 19, 1918	2.78	0.59
203	Kearsarge, Inyo Co., Calif.	Jan. 28, 1918	2.81	1.45
215	Schurz, Nev.	Feb. 26, 1918	4.29	2.57
447	Benton, Calif.	Sept. 16, 1918	3.66	2.66
448	Benton, Calif.	Sept. 16, 1918	3.55	3.58
449	Benton, Calif.	Sept. 16, 1918	2.39	1.85
561	Basalt, Nev.	Dec. 21, 1918	3.67	0.94^x
562	Basalt, Nev.	Dec. 21, 1918	2.88	0.95^x
577	Near Barstow, Calif.	Dec. 24, 1918	2.12	0.26^x
578	Near Barstow, Calif.	Dec. 24, 1918	2.71	0.88
658	Quinn River Valley, Nev.	Jan. 1, 1918	3.30	1.88
711	Near Victorville, Calif.	Dec. 26, 1918	2.27	0.96
712	Near Victorville, Calif.	Dec. 26, 1918	2.96	1.80
778	West of Lancaster, Calif.	Mar. 13, 1919	2.72	1.23
779	West of Lancaster, Calif.	Mar. 13, 1919	2.30	1.20
780	West of Lancaster, Calif.	Mar. 13, 1919	2.40	0.76

MICROSCOPICAL EXAMINATIONS

	Place of Collection	Date of Collection	Estimated Amount
13	Pyramid Lake Road, Nev.	June 14, 1917	Fair
35	Pyramid Lake, Nev.	Aug. 16, 1917	Good
41	Mojave, Calif.	Oct. 25, 1917	Traces
42	Mojave, Calif.	Oct. 25, 1917	Poor
49	Lancaster, Calif.	Oct. 28, 1917	Poor
51	West of Owens Lake, Calif.	Oct. 29, 1917	Traces
53	Kearsarge, Inyo Co., Calif.	Oct. 29, 1917	Good
59	Independence, Calif.	Oct. 31, 1917	Good
63	West of Bishop, Calif.	Nov. 1, 1917	Poor
481	West of Mound House, Nev.	Sept. 23, 1918	Fair
482	Pyramid Lake, Nev.	Sept. 24, 1918	Nothing

Chrysothamnus nauseosus var. graveolens

Chemical Analyses

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
272	Ft. Collins, Colo.	July 7, 1918	2.84	0.67x
278	Trinidad, Colo.	Aug. 11, 1918	2.39	0.07
279	Trinidad, Colo.	Aug. 11, 1918	2.65	1.03
280	Trinidad, Colo.	Aug. 8, 1918	3.02	0.68
281	Trinidad, Colo.	Aug. 11, 1918	2.88	0.69
283	Purgatoir River, Colo.	Aug. 15, 1918	3.13	0.36
296	Cimarron, Colo.	Sept. 1, 1918	3.15	0.21
299	Near Grand Junction, Colo.	Sept. 1, 1918	2.03	3.19
411	Near Cedar City, Utah	Sept. 5, 1918	2.03	0.49
516	Green River, Utah	Oct. 18, 1918	2.88	0.87

Microscopical Examinations

	Place of Collection	Date of Collection	Estimated Amount
266	Vernal, Utah	July 1, 1918	Traces
288	Cañon City, Colo.	Aug. 6, 1918	Traces
297	Grand Junction, Colo.	Sept. 1, 1918	Traces
298	Grand Junction, Colo.	Sept. 1, 1918	Traces
401	Near Grand Junction, Colo.	Sept. 2, 1918	Traces
412	Near Cedar City, Utah	Sept. 5, 1918	Poor
497	Garden of the Gods, Colo.	July —, 1918	Poor

Chrysothamnus nauseosus var. hololeucus

Chemical Analyses

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
62	West of Bishop, Calif.	Nov. 1, 1917	4.00	4.10
451	Benton, Calif.	Sept. 16, 1918	2.87	1.03
452	Benton, Calif.	Sept. 16, 1918	2.98	3.98
453	Benton, Calif.	Sept. 16, 1918	3.14	2.22

Microscopical Examinations

	Place of Collection	Date of Collection	Estimated Amount
12	Pyramid Lake Road, Nev.	June 14, 1917	Traces
34	Pyramid Lake, Nev.	Aug. 17, 1917	Fair
58	Independence, Calif.	Oct. 31, 1917	Poor
65	Benton, Calif.	Nov. 5, 1917	Poor
91	Near Palmdale, Calif.	Jan. 19, 1918	Poor
483	Pyramid Lake, Nev.	Sept. 24, 1918	Fair

Chrysothamnus nauseosus var. **leiospermus**

CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
418	Near Caliente, Nev.	Sept. 6, 1918	2.82	0.84
529	Joseph City, Utah	Nov. 12, 1918	2.41	1.17x

MICROSCOPICAL EXAMINATIONS

	Place of Collection	Date of Collection	Estimated Amount
78	Near Candelaria, Nev.	Nov. 8, 1917	Traces
415	East of Caliente, Nev.	Sept. 6, 1918	Traces

Chrysothamnus nauseosus var. **mohavensis**

CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
550	Mt. Hamilton, Calif.	Dec. 15, 1918	2.05	0.30x
551	Mt. Hamilton, Calif.	Dec. 15, 1918	2.90	0.30x
552	Mt. Hamilton, Calif.	Dec. 15, 1918	2.79	1.08x
553	Mt. Hamilton, Calif.	Dec. 15, 1918	2.15	0.44x

MICROSCOPICAL EXAMINATIONS

	Place of Collection	Date of Collection	Estimated Amount
40	Mojave, Calif.	Oct. 25, 1917	Nothing
43	Southwest of Mojave, Calif.	Oct. 25, 1917	Poor
44	Southwest of Mojave, Calif.	Oct. 25, 1917	Traces
92	Near Palmdale, Calif.	Jan. 19, 1918	Poor

Chrysothamnus nauseosus var. **occidentalis**

CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
775	Near Tejon Pass, Calif.	Mar. 13, 1919	2.78	0.95
776	Near Tejon Pass, Calif.	Mar. 13, 1919	2.84	0.71
777	Tejon Pass, Calif.	Mar. 13, 1919	1.88	1.54

Chrysothamnus nauseosus var. **pinifolius**

CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
290	Alamosa, Colo.	Aug. 31, 1918	4.27	3.41
291	Alamosa, Colo.	Aug. 31, 1918	4.81	1.11
293	Salida, Colo.	Aug. 3, 1918	4.05	3.98
294	Salida, Colo.	Aug. 31, 1918	4.00	2.65x
788	San Luis Valley, Colo.	Mar. 15, 1919	3.62	3.59

MICROSCOPICAL EXAMINATION

	Place of Collection	Date of Collection	Estimated Amount
265	East of Roosevelt, Colo.	June 30, 1918	Traces

Chrysothamnus nauseosus var. speciosus

Chemical Analyses

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
229	South of Likely, Modoc Co., Calif.	Mar. 8, 1918	3.55	2.49
240	Near Weed, Calif.	June 6, 1918	2.43	1.52
245	Antelope, Ore.	June 16, 1918	3.83	2.77
248	Near Burns, Ore.	June 19, 1918	3.10	0.40
255	East of Hammett, Idaho	June 22, 1918	4.16	2.52
270	Rawlins, Wyo.	July 3, 1918	3.70	1.80x
405	Stockton, Colo.	Sept. 3, 1918	2.87	0.52
406	Stockton, Colo.	Sept. 3, 1918	2.39	0.44
407	Stockton, Colo.	Sept. 3, 1918	3.09	0.38
462	Warren Creek, Calif.	Sept. 20, 1918	3.98	0.58
465	Mono Lake, Calif.	Sept. 20, 1918	3.48	1.55
471	Near State Line Lake, Nev.	Sept. 22, 1918	3.37	0.49
495	Redmond, Ore.	Sept. 29, 1918	4.02	0.73
498	Lolo, Mont.	Dec. 4, 1918	2.75	0.77x
557	Reno, Nev.	Dec. 20, 1918	3.43	2.31x
559	Near Reno, Nev.	Dec. 20, 1918	2.31	0.62x
758	Spokane, Wash.	Feb. 18, 1919	3.49	0.16

Microscopical Examinations

	Place of Collection	Date of Collection	Estimated Amount
6	Truckee, Calif.	June 6, 1917	Traces
10	Boca, Calif.	June 18, 1917	Nothing
17	Ogden, Utah	June 19, 1917	Traces
20	Ogden, Utah	Aug. 7, 1917	Traces
21	Ogden, Utah	Aug. 7, 1917	Traces
25	Goldfield, Nev.	Aug. 10, 1917	Poor
27	Reno, Nev.	Aug. 14, 1917	Poor
37	Truckee, Calif.	Aug. 17, 1917	Nothing.
39	Reno, Nev.	Aug. 14, 1917	Poor
150	Redmond, Ore.	May —, 1918	Poor
161	Albuquerque, New Mex.	July 29, 1918	Poor
162	Modoc Co., Calif.	Nov. —, 1918	Poor
163	Modoc Co., Calif.	Nov. —, 1918	Fair
164	Modoc Co., Calif.	Nov. —, 1918	Fair
244	South of Roseburg, Ore.	June 8, 1918	Nothing
246	Near Antelope, Ore.	June 16, 1918	Traces
249	Near Burns, Ore.	June 19, 1918	Nothing
264	Near Duchesne, Utah	June 30, 1918	Traces
269	Southwest of Rawlins, Wyo.	July 7, 1918	Traces
435	Lida, Nev.	Sept. 10, 1918	Traces
464	Mono Lake, Calif.	Sept. 20, 1918	Nothing
488	Reno, Nev.	Sept. 25, 1918	Poor
501	Grantsville, Utah	Sept. 25, 1918	Poor
503	Grantsville, Utah	Sept. 25, 1918	Poor
511	Near Salt Lake, Utah	Oct. 7, 1918	Poor
512	Near Salt Lake, Utah	Oct. 7, 1918	Poor

Chrysothamnus nauseosus var. **viridulus**

CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
54	Kearsarge, Inyo Co., Calif.	Oct. 29, 1917	3.90	4.84x
64	Benton, Calif.	Nov. 3, 1917	3.74	5.56x
80	Near Benton, Calif.	Nov. 10, 1917	3.56	2.00
133	Benton, Calif.	Feb. 15, 1918	4.12	3.64x
134	Near Benton, Calif.	Feb. 17, 1918	3.73	2.18
211	Fish Lake Valley, Nev.	Feb. 25, 1918	5.65	2.00
212	Near Oasis, Nev.	Feb. 25, 1918	5.02	0.96
428	Beatty, Nev.	Sept. 8, 1918	2.40	2.70
434	Lida, Nev.	Sept. 10, 1918	2.57	1.67
439	Near Deep Spring Valley, Calif.	Sept. 12, 1918	2.22	2.39
441	Benton, Calif.	Sept. 16, 1918	2.80	2.31
442	Benton, Calif.	Sept. 16, 1918	3.18	3.97
443	Benton, Calif.	Sept. 16, 1918	2.52	3.11
444	Benton, Calif.	Sept. 16, 1918	2.60	3.83
445	Benton, Calif.	Sept. 16, 1918	3.13	5.29
446	Benton, Calif.	Sept. 16, 1918	3.61	4.16
450	Benton, Calif.	Sept. 16, 1918	2.50	2.09
459	Near Mono Lake, Calif.	Sept. 19, 1918	3.64	1.79
467	Near Mono Lake, Calif.	Sept. 22, 1918	3.71	1.74x
468	Near Mono Lake, Calif.	Sept. 22, 1918	2.88	0.65
563	Near Benton, Calif.	Dec. 21, 1918	3.38	0.52
565	Benton, Calif.	Dec. 21, 1918	2.64	0.58
570	Benton, Calif.	Dec. 21, 1918	2.92	1.09x
571	Near Benton, Calif.	Dec. 21, 1918	3.49	4.45x
572	Benton, Calif.	Dec. 21, 1918	3.04	4.00x
574	Near Benton, Calif.	Dec. 23, 1918	2.61	2.00x
576	Near Benton, Calif.	Dec. 23, 1918	6.85	3.93x
590	Near Victorville, Calif.	Dec. 25, 1918	2.70	2.43
704	Cushenberry Spring, Calif.	Dec. 25, 1918	3.21	1.02
705	Cushenberry Spring, Calif.	Dec. 25, 1918	2.13	1.30
706	Cushenberry Spring, Calif.	Dec. 25, 1918	2.08	1.34
718	Hesperia, Calif.	Dec. 26, 1918	1.94	0.44
748	Near Barstow, Calif.	Dec. 30, 1918	3.71	3.35
749	Near Benton, Calif.	Dec. 23, 1918	5.79	1.32
752	Mono Lake, Calif.	Feb. 1, 1919	3 47	3.75
755	Mono Lake, Calif.	Feb. 1, 1919	3.74	2.26

MICROSCOPICAL EXAMINATIONS

	Place of Collection	Date of Collection	Estimated Amount
47	Near Rosamond, Calif.	Oct. 27, 1917	Good
50	West of Owens Lake, Calif.	Oct. 29, 1917	Fair
55	Kearsarge, Inyo Co., Calif.	Oct. 29, 1917	Good
56	Kearsarge, Inyo Co., Calif.	Oct. 29, 1917	Poor
57	Kearsarge, Inyo Co., Calif.	Oct. 29, 1917	Good
60	West of Bishop, Calif.	Nov. 1, 1917	Good
79	Near Mina, Nev.	Nov. 9, 1917	Good
84	Laws, Inyo Co., Calif.	Nov. 13, 1917	Fair
88	West of Lancaster, Calif.	Jan. 19, 1918	Poor

X. DISTRIBUTION OF RUBBER IN THE PLANT

a. REGIONAL DISTRIBUTION IN THE PLANT

Since our main endeavors have been directed to an examination of a large number of individual plants of a number of species of *Chrysothamnus* and other genera, no great attention has been given to many interesting and perhaps ultimately important details which have to do with anatomical peculiarities and with the origin and occurrence of rubber, which, under other circumstances, might well have concerned us. Indeed, various causes have resulted in an accumulation of studies much less detailed concerning these matters than was originally anticipated. Again, since our interest lay primarily in discovering the average rubber content of the main rubber bearing tissues and since it was early seen that the latter were peculiar to the older parts of the stem, the younger portions of both stem and root, the study of which is necessary for a thorough elucidation of the problems of the origin and occurrence of rubber, were not usually collected in the field and were thus not available for study in many cases. At the present time, however, we are prepared to make certain general statements concerning the distribution of rubber in the plants with which we have been concerned, and leave for further description a number of matters which are still under investigation. Particularly, we aim in what follows to interpret for such persons as may concern themselves with histological examinations of plants suspected of containing rubber, the appearance of the sections which they will be likely to obtain and to indicate to them the nature and distribution of the tissues in which rubber may be expected to occur. In this endeavor we will emphasize the results of our histological studies, but will also draw upon those derived from chemical analysis.

Attention has already been called to the fact that as in Guayule, so in *Chrysothamnus* we are dealing with a non-latex rubber which is found deposited as such within the individual cells of certain portions of the plant body. It may be noted in passing that many persons, even at the present time, are not acquainted with the nature of the occurrence of rubber in Guayule, nor with the consequent processes of extraction, the latter differing so decidedly from those employed in the case of plants which bear latex-rubber. Since identical or similar processes will undoubtedly be employed should Chrysil at any time prove of sufficient importance to warrant its extraction on a

commercial scale, it may not be out of place to refer the reader to the description of the commercial process for the extraction of Guayule, given by Lloyd.[18]

With reference to the relative amounts and the general distribution of rubber in the various parts of the plant body certain points seem rather well established. This is an important matter since persons planning to extract Chrysil on a commercial scale would at the start wish to know which portions of the plant contain maximum quantities of rubber and should be harvested and which portions should be discarded as containing negligible quantities. The following table contains the results of such analyses as we have at hand bearing upon this matter.

TABLE 7.—RESULTS OF ANALYSES MADE TO INDICATE THE RELATIVE AMOUNTS OF RUBBER BORNE BY THE VARIOUS PARTS OF THE PLANT BODY—*Chrysothamnus*

Collection Number	Variety	Acetone Extract Per cent.	Benzene Extract Per cent.	Remarks
144 (1)	[1]C. n. consimilis	3.75	0.81	First 10 cm. up from end of root
(2)		3.59	2.12	10 cm. section, from first rootlets to soil line
(3)		3.69	1.74	Main branches, 4 to 8 years old at bases and 30 cm. long
(4)		4.64	1.85	Tops of branches, 3 to 4 years old at bases, 2 years old at tops
752 (1)	[2]C. n. viridulus	3.47	3.75	At soil line
(2)		11.80	1.70	2 year old shoots
(3)		22.57	0.42	Tops, 1 year old
755 (1)	[2]C. n. viridulus	3.74	2.26	At soil line
(2)		15.10	1.63	2 year old shoots
(3)		19.80	0.74	Tops, 1 year old
620 (1)	[3]C. n. consimilis	2.89	0.13	End of root, 10 cm.
(2)		3.54	0.28	Next 10 cm. up root
(3)		2.99	0.37	Third 10 cm. up root
(4)		2.89	0.43	Fourth 10 cm. up root
(5)		3.46	3.03	Soil line
(6)		2.79	1.54	First 7 cm. up from soil line
(7)		2.97	1.91	Second section up from soil line, 8 cm.
(8)		3.24	2.07	Third section up from soil line, 8 yrs. old
(9)		3.16	2.20	Fourth section, 7 years old
(10)		3.43	1.91	Fifth section, 6 years old
(11)		2.79	2.20	Sixth section, 5 years old
(12)		2.86	2.77	Seventh section, 4 years old

[1] Collected, Golconda, Nev., Mar. 4, 1918.
[2] Collected, Mono Lake, Feb. 1, 1919.
[3] Collected, Ely, Nev., Feb., 1919.

[18] *L.c.*, p. 8.

TABLE 7.—(*Continued*)

Collection Number	Variety	Acetone Extract Per cent.	Benzene Extract Per cent.	Remarks
(13)		2.80	2.43	Eighth section, 3 years old
(14)		6.12	1.63	Shoots, 2 years old
(15)		13.79	1.27	Shoots, 1 year old
(16)		20.33	1.01	Tips, current year
622 (1)	[3]C. n. consimilis	4.72	0.36	End of root, 30 cm.
(2)		4.59	0.35	Next 10 cm. up root
(3)		4.26	0.48	Next 10 cm. up root
(4)		5.49	0.96	Next 10 cm. up root
(5)		2.15	1.56	Next 10 cm. up root
(6)		2.15	2.36	Soil line
(7)		3.42	2.12	Main branches, 5 to 6 years old.
(8)		2.65	1.88	Main branches, 4 to 5 years old
(9)		3.29	1.64	Main branches, 3 to 4 years old
(10)		4.52	2.39	Main branches, 2 to 3 years old
(11)		5.52	0.96	Shoots, 2 years old
(12)		10.72	0.83	Shoots, 1 year old
(13)		2.12	0.86	Tips, current year.

[3] Collected, Ely, Nev. Feb., 1919.

For convenience of discussion the table above has been differently arranged and somewhat condensed in the table which follows:

TABLE 8.—THE RELATIVE AMOUNTS OF RUBBER FOUND IN VARIOUS PORTIONS OF THE ROOT AND IN PORTIONS OF THE STEM OF VARIOUS AGES

Collection Number	144	752	755	620	622
End of root	0.81	....	....	0.13	0.36
Root up to soil line (av.)	....	....	....	0.32	0.83
Soil line	2.12	3.75	2.26	3.03	2.36
Base of main stems, 6 years old and older	1.74	....	....	1.93	2.12
Stems, 4 to 5 years old	....	....	....	2.48	1.88
Stems, 3 to 4 years old	1.85	....	....	2.60	1.64
Branches, 2 to 3 years old	....	....	....	2.03	2.39
Branches, 2 years old	....	1.70	1.63	1.63	0.96
Branches, 1 year old	....	0.42	0.74	1.27	0.83
Tops, current year	....	....	....	1.01	0.86

These data indicate that in *Chrysothamnus* the root proper (below a point from six to eight inches below the soil line) contains little or no rubber. In addition to the two species for which analyses are given in tables 7 and 8 we have analyses comparing the rubber content of stem and root in the case of *gnaphalodes* and *pinifolius* which give results closely similar to those above. Attention should here be called to the fact, discussed in detail elsewhere (p. 274) that

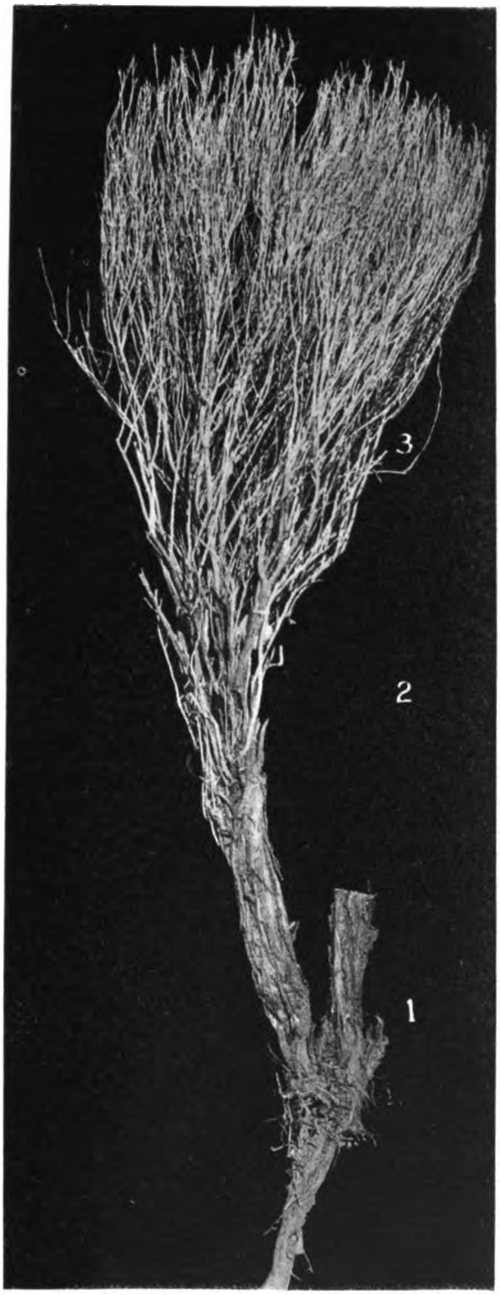

Fig. 5. A large plant of *Chrysothamnus nauseosus* var. *viridulus*. 1 indicates the assumed soil-line; 2 the upper limits of the main trunk; 3 the approximate upper limits of the three- to four-year-old wood.

in certain species of *Haplopappus* rubber is confined to the root or occurs in approximately equal amounts in root and stem.

As far as stem structures are concerned it is more difficult to indicate a sharp line of demarcation between those which are significant and those which are not significant as far as rubber content is concerned. Figure 5 shows a large plant of *viridulus* (no. [illegible]) and serves to indicate the characteristic method of branching and the general configuration of plants of this and other varieties which we have examined.

The assumed soil line, the upper limits of the main trunk, and the approximate upper limits of the three- to four-year-old wood are shown. The results listed in tables 7 and 8 suggest that only such parts of the plant as lie between 1 and 3 contain sufficient rubber to warrant their harvesting if the plants were used as a commercial source of rubber.

In the various tables above and in those which follow, analyses of portions

of plants furnish the data on the basis of which a certain percentage rubber content is assigned to a given individual. Figure 4 shows plants trimmed for grinding and analysis and it is apparent that what is left of the plants represent areas roughly equivalent to the portion between 1 and 2 in figure 5.

It appears from tables 7 and 8 that maximum quantities of rubber occur at the soil line. In the case of future examinations of plants to get at the per cent of contained rubber it would appear that this basal portion of the main trunk alone might furnish a characteristic sample and that the whole area between 1 and 3 (fig. 5) need not be handled. In other words analysis of a soil line sample of such a plant as 620 (table 7, 620 (5)) indicated that approximately 3 per cent of rubber was present and it is held that this figure may safely be taken as a fair approximation of the per cent borne by the entire plant exclusive of the root and the shoots and twigs less than three or four years old. At first sight it would appear that this figure is too high since table 7 indicates that an average percentage content of segments (5) to (13) of 620 would approximate 2 rather than 3 per cent. In this connection, however, the relative weights of the areas between 1 and 2 (cf. fig. 5) and between 2 and 3 must be taken into account. A number of weighings indicate that the weight of that portion between 2 and 3 is approximately 30 per cent of the total weight of the region between 1 and 3. This total weight will roughly approximate 1500 grams. It appears from the data given that if the main trunk bears in the neighborhood of 3 per cent the branches up to the limits of the three to four year old wood will bear about 2 per cent. With this assumption in mind the following relation appears to hold good:

Weight 1 to 2 = 1150 gm., which at 3% = 34.50 gm. rubber.
Weight 2 to 3 = 450 gm., which at 2% = 9.00 gm. rubber.

Total weight = 1500 gm., total rubber = 43.50 gm.
Total weight = 1500 gm. at 3% = 45.00 gm. rubber.
Total weight = 1500 gm. at 2% = 30.00 gm. rubber.

Based upon such rough estimates as these it seems clear that, due to the greater weight of the main trunk as compared with the older branches, a report of per cent of contained rubber based upon an analysis of portions of the plant near the soil line would not give a wholly erroneous estimate of the amount of rubber to be obtained from a plant harvested so that parts from 1 to 3 (fig. 5) alone were retained.

As stated above we have been unable to secure a sufficiently large number of analyses of the younger and older portions of plants to make our conclusions as to regional distribution of rubber entirely authoritative. The surprising decrease in rubber content a short distance above the soil line is perplexing as is the succeeding increase in the upper portion of the main trunk and branches. Elimination of the primary cortex by peridermal activity in the older trunk elements is obviously not an adequate explanation since at the soil line maximum elimination of cortical tissue has taken place. Indeed, cork formation with the accompanying distintegration of rubber cut out thereby has progressed to a decided extent before the third year of growth. The results obtained suggest, among other things, a translocation of rubber or its derivatives. Such implications deserve nothing more than a mere mention when the data are so fragmentary.

b. SPECIFIC DISTRIBUTION IN MATURE TISSUES

In an earlier paragraph it was stated that for making a rough estimate under the microscope of the amount of rubber borne by a given plant, a piece of mature tissue was cut from the main stem axis. For convenience we may use as the basis for a description of the tissues in which rubber, if present, may be expected to occur, the accompanying photomicrographs and photographs of stained preparations. As will be noted in plates — and — the stained areas are for the most part extracambial although the rays are also conspicuously stained. Analyses of one plant indicate that the amount of rubber in the cortex as compared with that in the woody cylinder is in the ratio of approximately six to one.

Not all the stained areas without the cambium are rubber bearing, however. Sudan III stains intensely the walls of corky tissues and the superficial portions of the stained material outside the woody cylinder represent cork and bark. Within this outermost layer the broad wedge-shaped extensions of the primary rays are most conspicuously stained. In a plant bearing from 4 to 5 per cent of rubber all the cells of these ray extensions are filled with rubber inclusions. Indeed in microscopical examinations of *Chrysothamnus* these areas should first be examined for the presence of rubber as, uniformly, in sections of stems over two years old, stainable rubber inclusions, if present at all, will here be found.

Bands of stained tissue will be seen connecting tangentially the cortical ray extensions. These represent the parenchymatous elements

of the cortex and non-functional phloem increments. The functional phloem areas are also rubber bearing although in this case the protoplasmic matrices of the cells often stain in simulation of rubber inclusions. The sieve tubes and companion cells are quite small in cross-sectional diameter and only in longitudinal sections can rubber globules be identified within them. The phloem parenchyma bears the largest amount of rubber in the phloem area and even in cross-sectional view there is no difficulty in identifying the stained inclusions as such.

The cambium appears consistently to bear rubber inclusions in stems more than one year old. The rubber is in the form of small globules which seem to increase in number during cambial activity. As an annual cambium increment toward the periphery begins to become differentiated into characteristic phloem elements these small globules tend to agglomerate. Intracambially, however, the partially differentiated xylem elements contain no rubber inclusions although originating from the same rubber bearing cambium which passes on its rubber inclusions to the developing phloem increments. This situation might furnish a starting point for investigations on the chemical or physical constitution of the protoplast which is specific for the differentiation of rubber inclusions or essential for the permanence and persistence of such inclusions. In none of the mature xylem elements, parenchymatous or otherwise, have rubber inclusions been found.

Under the microscope one of the most conspicuous features which attracts attention when preparations such as those shown in plates 18 and 19 are examined is the increase in rubber deposition at certain points along the rays. Although this matter is not well brought out in all the photographs it may still be seen that at points corresponding to the spring wood of each annual xylem increment the amount of rubber is less than at those points along the rays which correspond to the summer or fall wood. This situation will be mentioned elsewhere in connection with a discussion of seasonal variation in rubber content.

Plates 18 and 19 (exclusive of figures 4 and 5) show cross sections of stems of various ages. The stem of the current year shown in plate 18, figure 1, is included to call attention to the deep staining of the chlorenchyma, the absence of stainable substance in cortex and rays, and especially the large quantity of stained rubber in the xylem intrustion of an axillary bud. The three year old stem in plate 18,

figure 3, illustrates the statements made above as to the conspicuous staining of the cortical ray extensions and the presence of rubber in the phloem and rays. It will be noted that the portions of the rays lying in the first annual increment contain relatively negligible amounts of rubber as compared with the portions of the rays lying in the second and third year xylem. The line "C" marks the approximate limits of the living cortex.

Figure 2 in plate 18 is included to show the extent of the rubber bearing tissues and of the non-rubber bearing cork and barky elements. The "A" line indicates roughly the external limits of the rubber bearing cortex. Cork has formed below this line but the primary cortical tissues cut out thereby show rubber not yet entirely disintegrated. The "B" line points to the tangential strip in which maximum quantities of rubber occurring in the cortical parenchyma and in the cortical ray extensions may ordinarily be expected to occur. Figure 2 is a cross section of a five year old stem.

In plate 19 the two cross sections give evidence as to the distribution of rubber in mature stems. Figure 1 was cut from a six year old stem and figure 2 from a nine year old stem. The greater portion of the bark and inner cork is absent in figure 1 and it will be seen that the cortical ray extensions filled with rubber extend outward for a long distance. The broad ray extension on the extreme left in figure 1 is characteristic of many of the cortical extensions of the primary rays and its cells are densely packed with rubber.

Figure 2 in plate 18 shows a particularly thin section from which in places the rubber inclusions have fallen or have been washed out. Line "A" indicates roughly the limits of the rubber bearing tissues; those external being composed largely of cork and bark.

We have found that rubber is present in the cell either in what may be spoken of as a "diffused" state or in the form of globules. In the diffused state the entire cell cavity is filled with a mass of stained substance which appears to be somewhat homogeneous. This condition is shown in certain of the cells in plate 18, figure 4, the spherical globules representing detached masses of rubber which have rounded up when free from the cell wall. When present in globular form, one or more large spherical globules partially fill the cell cavity or a number of smaller definitely spherical globules are distributed without apparent arrangement within it. Spherical globules *in situ* are shown in a number of the cells in plate 18, figure 5. For a time it seemed possible that the form in which the rubber occurred in the

cell might serve as one of a number of bases for species differentiation in *Chrysothamnus.* Certainly *C. teretifolius* (cf. p. 266) consistently exhibits rubber only in the form of large spherical globules which usually occur singly and almost exclusively in the cells of the cortical

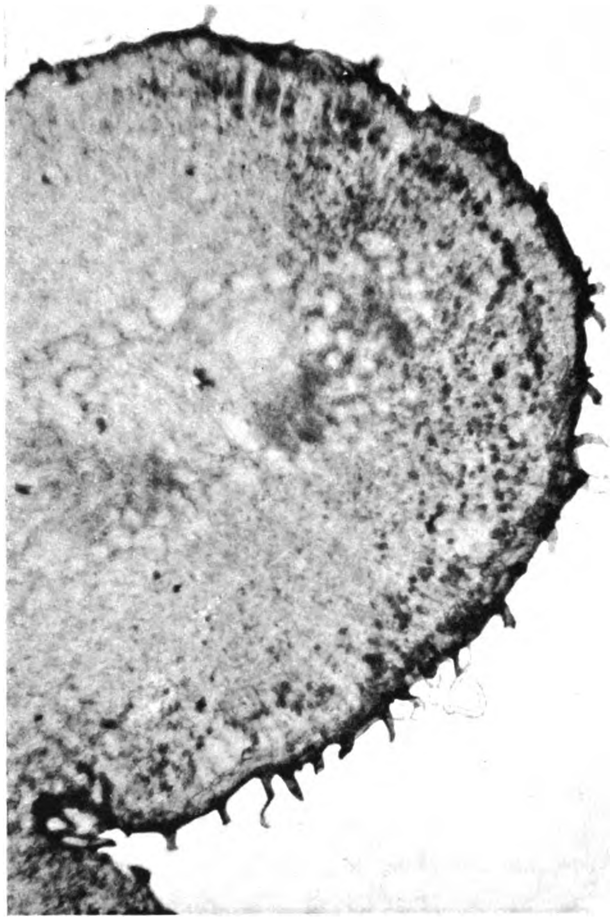

Fig. 6. Portion of a cross-section of a mature leaf of *Chrysothamnus nauseosus* var. *consimilis.* Plant grown in the University of California Botanical Garden, Berkeley. Photo-micrograph.

parenchyma. In the *nauseosus* group a number of globules often are present in the cells of young rubber bearing tissues but they tend to agglomerate with age so that the corresponding tissues when mature show few if any globular rubber inclusions, this substance being present in the "diffused" condition. Such a condition does not obtain

for *teretifolius,* globules only being found both in younger and older elements. The cross section of a leaf of a plant grown in the University of California Botanical Garden is shown in figure 6. The dark stained rubber globules in the palisade cells are conspicuous. Lloyd[18a] reports that a single large globule of rubber was characteristic of each palisade cell in certain portions of the leaf in Guayule. A corresponding condition holds for *Chrysothamnus* although in some instances it appears that more than one globule may occur in a single palisade cell. Various problems dealing with the origin of rubber and its distribution in younger tissues have been investigated in a preliminary way, at least. The results of these studies will be published in the near future as the fourth paper of the present series.

XI. FACTORS INFLUENCING RUBBER CONTENT

a. VARIATION WITH THE BOTANICAL VARIETY

The results of our studies, more particularly the chemical and microscopical examinations, indicate that rubber is present in only a few of the major species of *Chrysothamnus.* The species examined and in which it was not found with certainty are: *C. Greenei, C. Howardi, C. nevadensis, C. Parryi, C. humilis, C. puberulus,* and *C. viscidiflorus.* In *C. linifolius,* which is perhaps only a variety of *viscidiflorus,* it was found to the extent of 1 per cent in one sample but was lacking in another. The species of *Chrysothamnus* now known to yield rubber are *C. nauseosus, C. turbinatus, C. teretifolius,* and *C. paniculatus.* The last three of these are discussed elsewhere since they are of minor importance and the product is not Chrysil.[19]

Coming now to a consideration of *C. nauseosus,* we find that this variable and widespread species breaks up into about twenty-two varieties. It may be predicted with reasonable certainty that Chrysil will be found in all of these twenty-two forms. This statement is based upon the fact that of the thirteen thus far investigated every one has yielded a greater or less amount of this substance. It might be assumed, *a priori,* that certain of these botanical varieties would carry a consistently higher percentage than others. This assumption is borne out to some extent by the analyses, as is indicated in the following summary of the analytical tables published in detail on pages 226 to 233.

[18a] *L.c.,* p. 184.

[19] See pp. 265–268.

Summary of Table 6

	Variety	Number of samples analyzed	Rubber in poorest sample Per cent.	Rubber in best sample Per cent.	Average of all samples Per cent.
1	consimilis	69*	0.39	6.57	1.97*
2	viridulus	36	0.44	5.56	2.52
3	gnaphalodes	18	0.26	3.60	1.61
4	speciosus	17	0.16	2.77	1.18
5	graveolens	10	0.07	3.19	0.83
6	pinifolius	5	1.11	3.98	2.95
7	hololeucus	4	1.03	4.10	2.83
8	mohavensis	4	0.30	1.08	0.53
9	occidentalis	3	0.71	1.54	1.07
10	leiospermus	2	0.84	1.17	1.00
11	frigidus	1	....	....	1.86
12	nauseosus (typical)	2	(microscopical examination only)		traces

*Others included in the complete table are here omitted since the samples were imperfect.

In making use of this table it is better to take into account only the first five varieties since the others are not represented by a sufficiently large number of samples to render the results dependable. "Individual variation" is an important factor and it is only after a large number of samples from widely separated localities have been analyzed that one is justified in drawing conclusions.

Taking then only the first five varieties it would seem that they would stand, as to rubber content, in the order of *viridulus, consimilis, gnaphalodes, speciosus, graveolens.* While this may be of significance, it is also to be noted that the first two are inhabitants of alkaline flats, the next two belong to non-alkaline slopes, and the last (as far as our samples are concerned) to only moderately if at all alkaline soil. It may be, therefore, that an apparent parallel between rubber content and botanical varieties is, in fact, due to environmental factors.

While, as just shown, there is no direct evidence that the botanical varieties represent hereditary units, each with a different capacity for rubber production, there is nothing, on the other hand, to indicate that each variety may not itself be composed of several or even numerous biotypes. If this is the case, then the separation of these through selection might lead to the discovery of a superior strain. The notable fluctuation in the rubber content of any one variety might seem to indicate this possibility but the alternative as to the influence of environment must also be kept in mind.

b. VARIATION DUE TO ENVIRONMENT

Attempts have been made to correlate the differences in the rubber content of individual plants with various factors of the environment. This has not led, as yet, to positive conclusions. One reason for the failure to obtain definite results is the low percentage in even the best plants, so that any slight variation in the selection, preparation, or analysis of any two samples might more than offset any original difference in their composition. Only through extensive experimental work, can conclusive results be hoped for.

Notwithstanding the difficulties just mentioned, a few observations may be permitted. The water content of the soil is often considered to exert an influence on rubber deposition in plants. Specimens of a single variety of *Chrysothamnus nauseosus* selected to determine this point did not vary widely in the amount of Chrysil present. There was, if anything, a slight balance in favor of those growing on moist banks but this difference was so slight that it is probably of no significance. However, when different varieties are considered, and only the average of a large number of samples taken into account, it is found that those varieties which inhabit the moist and poorly drained valley bottoms contain rubber in larger amounts than do the varieties of the very arid and well drained surrounding slopes.

This is indicated by the table on page 244. The varieties there numbered 1, 2, and 6 are lowland forms and these run higher in rubber content than do numbers 3, 4, 8, 9, 10, 11, and 12, which are upland forms. The single apparent exception to this rule is number 7, but this may be due to the small number of samples analyzed for that variety.

But, while the formation of rubber thus seems to be favored by the more abundant moisture of the lowlands, another factor may be the real cause of the increase in percentage, namely, the presence of alkali. It is not impossible that the alkali acts indirectly through the water relation. It is well known that its presence reduces the amount of water available to plants, and it is conceivable that by thus lowering the chresard it causes a deficiency in physiological moisture which is even greater than the deficiency on the surrounding slopes. However this may be, it is certain that the best rubber producing varieties of *Chrysothamnus nauseosus* are those of the alkaline valley bottoms.

As to temperature, it seems unlikely that this factor exerts an influence on rubber formation except as it acts through other agencies.

There is no striking difference between the percentages found in the plants from the hot desert valleys of California and the cold mountain valleys of Colorado. The apparent running down of rubber content as one approaches the limits of distribution for the species is perhaps to be accounted for on other grounds. If temperature were the controlling factor it would be difficult to explain the uniformly low rubber content of plants from the warm Coast ranges of California and also of the cool plateaus at the eastern base of the Rockies.

The effect of wounds and of pruning may be a matter of much importance in case the plants are ever brought under cultivation. The wild shrubs are often riddled by the attacks of larvae and beetles, but their influence, if any, is not known. Experiments now in progress have already determined that the plants may be pruned back without injury and that this greatly increases the number and weight of the rubber bearing stems. The possible effect upon the formation of rubber will be determined later. (See plate 20.)

c. SEASONAL VARIATION

In the case of Guayule a variety of evidence points to the fact that there exists a striking seasonal variation in rubber content. Thus. it has been found that during the active season of growth only negligible quantities of rubber are deposited while during the following resting period rubber makes its appearance in the tissues. These two periods are correlated with the duration of the rainy season in the desert region where Guayule grows wild. During the rains growth is initiated and continues for a time. Shortly after the start of the dry season active vegetative growth ceases and rubber then begins to be deposited in the recently formed tissues.

With these facts in mind some experiments were made to determine whether a similar situation holds for rubber deposition in *Chrysothamnus*. Table 9 gives the results of these experiments. On September 16, 1918, portions of mature tissues were cut from thirteen plants representing three different varieties of *nauseosus* growing in a small tract near Benton, California. Notes and photographs made it possible on December 22, 1918, to remove from the same plants portions apparently equivalent to those which had been secured in September. There was no evidence that the removal of the first portion had in any way impaired the remainder of the plant or impeded its normal development. The September date is taken to represent the close of the growing period at which time the flowers

are produced. By the end of December the resting period is practically at an end since shortly thereafter the early spring growing season begins.

TABLE 9.—SEASONAL VARIATION IN RUBBER CONTENT OF THREE VARIETIES OF *Chrysothamnus nauseosus*

(September 16, 1918, represents the close of the growing season and December 22, 1918, the close of the resting season.)

	Variety	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
441	C. n. viridulus	Benton, Calif.	Sept. 16, 1918	2.80	2.31
		Benton, Calif.	Dec. 22, 1918	3.16	2.86
442	C. n. viridulus	Benton, Calif.	Sept. 16, 1918	3.18	3.97
		Benton, Calif.	Dec. 22, 1918	3.58	3.77
443	C. n. viridulus	Benton, Calif.	Sept. 16, 1918	2.52	3.11
		Benton, Calif.	Sept. 16, 1918	2.18	3.27*
		Benton, Calif.	Dec. 22, 1918	2.82	3.06
		Benton, Calif.	Dec. 22, 1918	2.97	2.95*
444	C. n. viridulus	Benton, Calif.	Sept. 16, 1918	2.60	3.83
		Benton, Calif.	Dec. 22, 1918	2.80	2.63
445	C. n. viridulus	Benton, Calif.	Sept. 16, 1918	3.13	5.29
		Benton, Calif.	Dec. 22, 1918	3.13	3.49
446	C. n. viridulus	Benton, Calif.	Sept. 16, 1918	3.61	4.16
		Benton, Calif.	Dec. 22, 1918	3.87	3.97
447	C. n. gnaphalodes	Benton, Calif.	Sept. 16, 1918	3.66	2.66
		Benton, Calif.	Dec. 22, 1918	3.43	1.52
448	C. n. gnaphalodes	Benton, Calif.	Sept. 16, 1918	3.55	3.58
		Benton, Calif.	Dec. 22, 1918	4.76	3.95
449	C. n. gnaphalodes	Benton, Calif.	Sept. 16, 1918	2.39	1.85
		Benton, Calif.	Dec. 22, 1918	2.79	0.99
450	C. n. gnaphalodes	Benton, Calif.	Sept. 16, 1918	2.50	2.09
		Benton, Calif.	Dec. 22, 1918	2.63	1.65
451	C. n. hololeucus	Benton, Calif.	Sept. 16, 1918	2.87	1.03
		Benton, Calif.	Dec. 22, 1918	3.44	0.79
452	C. n. hololeucus	Benton, Calif.	Sept. 16, 1918	2.98	3.98
		Benton, Calif.	Dec. 22, 1918	4.77	4.06
453	C. n. hololeucus	Benton, Calif.	Sept. 16, 1918	3.14	2.22
		Benton, Calif.	Dec. 22, 1918	3.98	2.12

*Duplicate analysis.

It seems probable from the results listed above that during the resting period the resins and other acetone-soluble substances increase in amount while the amount of rubber is diminished. This situation is unexpected in view of the reverse condition described above for Guayule. It is, also, of particular interest when the influence of storage of shrub upon resin and rubber content is recalled (cf. p. 224). In the case of storage the per cent of resins was considerably reduced along with a slight reduction in per cent of rubber. Obviously there

is need of further experiments and analyses to confirm the results of the more or less preliminary experiments tabulated above. Indeed a few exceptions to our general conclusion appear in table 9 and while not numerous enough to affect it materially certainly cast some doubt upon it. It is entirely possible that in selecting the two dates for collection of samples the critical period may have been overlooked. Thus, if a sample had been taken in August or earlier as well as in September a decided increase in rubber content might have been noted for the latter date. This would have meant that the flowering period in *Chrysothamnus* represents, in terms of seasonal variation in rubber content as observed for Guayule, not the end of the growing period but the beginning of the resting period during the start of which maximum deposition of rubber takes place very rapidly.[20] Had such collections been made and such results obtained no light would, however, have been thrown upon the seeming disappearance during the resting period of a certain proportion of the rubber present within a month of its start.

XII. METHODS OF HARVESTING: SEASON, AGE, DEPTH OF CUTTING, ETC.

The methods of harvesting have not been worked out in detail since it has not been demonstrated that *Chrysothamnus* can be utilized on a commercial scale. However, our preliminary studies have indicated certain general principles to be observed in case rubber is ever prepared from the plants and they are here set forth as follows.

The question of the distribution of rubber in the various plant organs and the extent of its occurrence in stems of various ages is discussed elsewhere (cf. p. 234). It may here be said that the amount of rubber in parts less than three years old is relatively small. From the third year onward for one or two years the amount increases rather rapidly. After the fifth or sixth year the quantity of rubber present remains more or less constant. The cause of this constancy in amount depends upon certain facts taken up in detail elsewhere. In the first place, the extracambial tissues are almost the exclusive regions of rubber deposition. Secondly, when cork formation takes place there is, each year, an amount of rubber containing cortical tissue cut off which roughly approximates the amount of new cortical tissue annually

[20] The microscopical evidence (cf. p. 240) appears to give a partial confirmation of such a supposition.

laid down. Finally, with the appearance of the phellogen deep in the cortex and the production by it of a few layers of cork the rubber in the cells external thereto begins to degenerate and soon loses its characteristic staining capacity. It is true, of course, that the annual increments added intracambially to the primary medullary rays and which in part are devoted to the origination of secondary rays increases each year the number of cells in the woody cylinder available for rubber deposition. There is in this case, obviously, no such annual reduction in the amount of rubber bearing tissues as is characteristic of the cortex. The amount of new rubber bearing tissue added each year to the existing ray material is so small and the quantity of rubber present in the individual ray cells is so relatively diminutive, that this source of increase in the rubber content of old as compared with younger stems is negligible.

The problem of a seasonal or periodic deposition will require for its final solution a much more detailed study than we have been able to give to it. The experiments mentioned on page 246 seem to indicate that the maximum amount of rubber is present near the close of the growing season. If these results are confirmed they will have a directive influence in determining the season at which harvesting should take place. This probably would not be a determining factor in selecting the season for harvesting wild shrub, but it might mean the difference between financial success and failure when the handling of cultivated plants is under consideration.

It would follow from the foregoing that old plants would be the best rubber producers. It is evident that as the plant becomes overmature decay sets in and reduces the weight of the rubber carrying portions. This is borne out to some extent by the results of our analyses, which indicate that the average percentage composition is about the same for large old plants as for medium sized plants of moderate age. Young plants, say four years old or less, are almost always low in percentage content, a direct result of the fact that deposition is small until about the third year and the ratio of rubber bearing tissue to the whole plant is therefore low. This discrepancy gradually disappears with age. It is quite certain that shrub which has reached maturity, that is, six to ten years for the *viridulus* form, bears its maximum quantity of rubber.

The depth at which the plants may be cut in harvesting without destroying the power of regeneration is a matter which has received considerable attention because of its practical bearings. Histological and

chemical analyses of the root indicate that it carries its highest percentage of rubber at about the surface of the soil and that the percentage rapidly diminishes downward, until at an average depth of about four inches the amount present is so small that the remainder of the root is of no value. In harvesting, it would therefore be desirable to make the cut about four inches below the surface. Our experiments, performed on over three hundred plants of three leading varieties, have definitely determined, however, that if this is done, or if the root is cut off anywhere below its junction with the stem, the portion remaining in the soil will die. The obvious explanation of this phenomenon is that, as in most plants, new shoots arise only from stem tissue. In all cases where the stems were cut off just above the soil surface the stumps promptly sent up an abundant growth of new shoots. In one case a diagonal cut was made just at the surface so that about an inch of stem was left on one side of the stump, while on the opposite side the cut extended to about an inch below the top of the root. After a lapse of six months there was a copious growth of shoots two feet long from the higher side of the stump, none at all from the lower.

The line of demarcation between stem and root is not a sharp one. A microscopic examination for dormant buds is, of course, impractical in field work; the bark is so similar on the lower part of the stem and the upper part of the root that its texture and color furnish no clue; and the soil level cannot be accepted as a criterion since it is easily modified by disturbing agencies such as erosion, deposition, accumulation of vegetable matter, and the activities of rodents. In most cases, a cut made just at the first crotch, which is usually also at the original soil surface, will safely provide for regeneration but much experience will be necessary if one desires to obtain the maximum amount of rubber and at the same time be assured of new growth without replanting. In case the wild shrub is ever utilized for an emergency supply of rubber it will probably be best to make the cut at about six inches below the surface, thus sacrificing the roots for the sake of the rubber in their upper portions; on the other hand, if *Chrysothamnus* is grown as a field crop it will probably be found profitable to provide for vegetative reproduction, either by leaving an inch or so of stem or by leaving portions of several of the lower branches as a foundation for a larger and broader plant.

The bulk of the shrub may be materially reduced without much loss of rubber by cutting off and discarding all growth less than three

years old. Wood which is just in its second year may or may not be worth preserving, depending upon methods of milling, local conditions, and the value of the rubber. The age is easily determined in young stems by counting the growth rings. The color and texture of the bark may also be used as a guide by one familiar with the plant. The removal of all growth of less than three years will take with it all of the leaves, but these, like the twigs themselves, carry only traces of rubber.

XIII. POSSIBILITIES OF *CHRYSOTHAMNUS* AS A CULTIVATED PLANT

It is eminently desirable that a portion of the rubber consumed in the United States should be produced within our own borders. It is the only important commodity essential to modern warfare which we have not yet learned to produce. If the industry of rubber growing were once established, even though it yielded only a fraction of our normal needs, we could, through economy in use and through governmental encouragement in war time, render ourselves independent of other nations, who might refuse to supply our needs or who might be unable to transport their products across the seas.

These same arguments can be advanced for the support of investigations looking to the production of synthetic rubber and there is no doubt that this line of work should also be encouraged. It is even possible that the synthetic product will in time replace that from the plantations. We are not in a position to forecast what the future may bring forth in this connection, but the opinion of those best capable of judging seems to be that high grade synthetic rubber in large quantities is something which we need not expect for a long time to come, if at all. In the meantime, dependence must be placed upon importations unless we can discover some commercially profitable method of growing rubber plants in our own country. The list of plants to be considered in this connection is a long one. It includes various exotics some of which are now grown in foreign countries for their rubber but none of which have been given a conclusive trial here. Certain of our native latex bearing plants, such as the milkweeds, spurges, dogbanes, etc., are now under investigation by the Carnegie Institution of Washington with some promise of success.[21] The Pinguay, or Colorado

[21] Carnegie Inst., Wash. Year-book no. 17 (1918), p. 297.

Rubber Plant (*Hymenoxys floribunda utilis*) has been unsuccessfully tried and the Guayule, a shrub native to our southern borders and to Mexico, is now under trial in Arizona. Since none of these rubber plants has as yet been agriculturally established in the United States it would seem worth while to give attention also to *Chrysothamnus* as a possible plant to be brought under cultivation for its rubber.

If a further incentive is needed for the study of rubber plants suitable to our conditions it may be found in the extent of unused and apparently unusable lands that are still to be found in our western states. The introduction of new agricultural industries for the proper utilization of these practically idle lands is one of the most important problems that now confront the people of the arid West. While we hesitate to predict that they will ever be used for the production of rubber, yet that this is within the realm of possibility is evidenced by the planting of a considerable acreage to Guayule in southern Arizona in 1918 by one of the leading rubber companies.

Guayule is a small Mexican shrub belonging to the same botanical family as the Rabbit-brush, although not very closely related to it. The similarity between the two is such that a consideration of the Guayule situation may furnish some evidence as to the possible worth of *Chrysothamnus*. The wild Guayule yields a "rubber" which had been imported into the United States in considerable quantity[22] before the political troubles in Mexico interfered with the industry. The supply of wild shrub was constantly on the wane, which led to extensive experiments in propagation, selection, breeding, and cultivation. The wild plants carry an average of 10 per cent of "Guayule gum," as it is called, but when they were brought under cultivation it was found that some plants yielded only 2 or 3 per cent, and in some cases less than 1 per cent, of pure rubber. The application of scientific methods of breeding and selection, together with the control of environmental conditions of growth have now brought the yield to as high as twenty-seven per cent in a few plants. We understand that these high percentage strains are not suitable for field growing but that those selected for planting on a large scale yield about fifteen to seventeen per cent of rubber in their fifth or sixth year.

These experiments with Guayule extended over a ten-year period and are said to have cost one company alone in the neighborhood of $500,000. Their promise, however, may be inferred from the present intention of the company to undertake planting in Arizona on a large

[22] (19,000,000 pounds in 1911.)

scale. Whether or not *Chrysothamnus* could be "improved" to the same extent is a question which we are unable to answer, for the two plants are so different in their life histories that methods used successfully with one might entirely fail with the other. Nevertheless it seems logical that the possibilities of both should be tested out before either one is exclusively selected for cultivation, since each possesses certain advantages which the other does not have. It is in order to draw a comparision between the two that the history of the introduction of Guayule into cultivation has been briefly outlined above.

The great superiority of Guayule lies in its high rubber content. As stated above, this averages ten per cent for wild plants as against an average of only 2.5 per cent for the *viridulus* form of *Chrysothamnus*. These figures are based upon pure dry rubber and dry shrub. Guayule, moreover, has been extensively studied; its habits, and its response to treatment, are at least somewhat understood, and the work thus far done upon it has resulted in the development of a fifteen to seventeen per cent strain. The improvement of *Chrysothamnus* could undoubtedly be brought about, at least to some extent, by selection and breeding. However, since it is presumably a cross fertilized plant, the separation of superior strains would be a more difficult matter than in Guayule. A starting point is indicated in that certain individuals of the variety *consimilis* actually ran as high as 6.7 per cent.

Guayule has a still further advantage in that the methods of field management, of milling, and of marketing are also established and the product is well known to the rubber trade. Here, however, the advantages of Guayule over *Chrysothamnus* seem to end.

As an offset against the above more favorable attributes of Guayule, and especially the higher rubber content, we find a number of points in favor of *Chrysothamnus*. These are here set down in order that the Mexican plant may be used to some extent as a gauge in measuring the possibilities of the other one.

(1) *Chrysothamnus* is a larger plant than Guayule, the wild shrubs averaging six pounds of rubber carrying wood, whereas the plants of the latter weigh one-half to three pounds, rarely attaining to six pounds.

(2) *Chrysothamnus* is a native of the western United States and is therefore adapted to our conditions. It grows where the temperature falls to zero and probably much lower, since it ranges up the mountains to over 7000 feet altitude. In the *consimilis* form it is known to grow over large areas where the temperature not infrequently

reaches — 20° F. Guayule, on the other hand, is too tender for any but our warmer valleys and even there its cultivation is apparently attended with some risk. Its introduction into this country is an extension of its natural range, whereas the cultivation of *Chrysothamnus* would be merely the utilization of a native plant adapted by nature to our region.

(3) *Chrysothamnus* is very resistant to alkali, often growing on soils too alkaline for any ordinary agricultural crop. It could therefore be grown on land not now utilized and which could be obtained for a very moderate price. Guayule is sensitive to alkali.

(4) The water requirement of *Chrysothamnus* is considerably less than that of Guayule. It could certainly be grown without irrigation on the cheap lands mentioned in paragraph 3.

(5) The product is superior to that of Guayule (see p. 188). It would bring a higher price in the market and if need arose would more nearly replace the fine imported rubbers in our industries.

(6) *Chrysothamnus* is more easily and cheaply propagated, both from seed, which form in abundance and are easily germinated, and vegetatively. Both old plants and seedlings may be transplanted without loss.

(7) Certain cultural practices have been developed in connection with Guayule that result in an increased yield of rubber, and methods of operation have been devised that permit of cheap handling through the use of machinery, so that the crop is said to be "machine-grown." There is no reason to suppose that similar practices and methods cannot be perfected for *Chrysothamnus*. The larger size of the shrubs and their habit of throwing up numerous new shoots when cut back indicate the possibility of increasing the tonnage of rubber carrying shrub by the cutting back of the tops (see pl. 20). Experimental work along these lines has not yet progressed to a stage where estimates would be warranted, but it is believed that a method can be worked out that will multiply by a considerable factor the tonnage of shrub per acre-year. It is possible that such manipulation may at the same time favor an increased formation of rubber in the tissues.

It would seem, therefore, that the possibilities of *Chrysothamnus* as a cultivated rubber plant should be looked into more closely. Any species which gives even the least promise should be thoroughly studied in order to find, if possible, a new crop that will turn our waste lands into productive fields and at the same time safeguard the nation against a possible deficiency in rubber during critical periods. These investi-

gations, as applied to *Chrysothamnus,* should be along several diverse lines, yet all leading to the same objective. They should include the following: detailed studies of wild plants for the purpose of discovering, if possible, better varieties or strains than we now have; garden experimentation in breeding and selection; modifications in environment, especially changes in the water relation, and the effect of methods of cultivation; the effect of varying amounts of alkaline salts on rubber deposition; and, finally, pruning and other experiments designed to test the possibility of increasing the amount of rubber bearing tissue and also of increasing the percentage in the tissues.

XIV. CULTURAL REQUIREMENTS

In case *Chrysothamnus* is brought under cultivation, its cultural requirements would need to be looked into very closely. At present, our knowledge of these is based upon observations of the wild shrub and upon a limited number of experiments in transplanting and in growing from seed.

These plants are not exacting as to their climatic requirements. The *viridulus* and *consimilis* forms grow readily from the lowest to the highest limits of the Upper Sonoran Life Zone and exceed these limits slightly in both directions. Expressed in another way, they range from fairly hot interior valleys, where the temperature runs to 110° F. in summer, to over 7000 feet in the mountains where snow falls to a depth of several feet and the temperature drops to — 20° F. in winter. No difficulty has been experienced in growing these varieties in the botanical garden at Berkeley, California, both from seed and from root transplants, but it is doubtful if they will grow here as rapidly or as large as they do under conditions of greater summer heat. Transplanted seedlings are also growing at the Citrus Experiment Station at Riverside, but they are not at all vigorous. It is not known whether this is due to the very unfavorable climatic conditions that prevailed when they were set out in the field or to some other factor. Moreover, Riverside is in the Lower Sonoran Life Zone and therefore perhaps too hot in summer for these Upper Sonoran plants. While the exact geographic limits for the cultivation of *Chrysothamnus* will need to be determined with some accuracy it seems reasonably safe to say that, as far as climate is concerned, it may be grown in any of the larger interior valleys of the West except perhaps those of the extreme north and the very hot Lower Sonoran valleys of the extreme south.

The moisture and soil requirements have not been carefully determined. As indicated above the most promising forms grow on valley bottoms where there is a moderate amount of moisture and where the soil is moderately to strongly alkaline. Salt-grass (*Distichlis*) is so common a concommitant of *viridulus* and *consimilis* that its presence undoubtedly indicates favorable soil conditions. That the plants can be grown with a minimum of precipitation is indicated by their abundance in places where the precipitation drops to below two inches in some years, but in these places it flourishes only on valley bottoms. The soil is always more or less sandy, but the plants grow readily, or at least make a satisfactory start, in the heavy clay of the botanical garden at Berkeley.

An ecologic consideration always to be kept in mind is that *Chrysothamnus* is not a strong competitor among plants. It is easily crowded out by other species, especially by Grease-wood if the alkali content of the soil is high and by Sage-brush if the alkalinity is slight, so that the area at present covered by it could be greatly extended through the removal of these more aggressive shrubs. That this is true as regards Sage-brush is attested by the experience of settlers who find that Rabbit-brush (especially the gray forms, *e.g.*, *gnaphalodes*) almost always takes immediate possession of the ground after the removal of the Sage-brush. This leads to the conclusion that the present occurrence of Rabbit-brush does not by any means represent the total area suited to its growth. It also indicates one rather simple method of extending the growth of the shrub, namely by removing its competitors.

In case the cultivation of *Chrysothamnus* is ever made a commercial success, the first plantations will presumably be located where the best varieties now grow wild. Aside from the assurance that such locations would provide the climatic, soil, and other requirements for successful growth, this would enable the management to utilize the wild shrub as a supplementary supply of crude rubber, although it would, of course, carry a lower percentage than the improved cultivated strains.

It is perhaps premature even to suggest districts where plantations might be located but the mention of a few may be not without interest. In Owens Valley, California, for example, it happens that the city of Los Angeles owns nearly 200,000 acres of land, partly covered with *Chrysothamnus* and not at present utilized except to a very limited extent for grazing purposes. It is estimated that at least one half of this is suitable to the growth of *Chrysothamnus* of the *viridulus* form.

Similarly, large suitable areas now partly covered with Rabbit-brush are located in Fish Lake Valley, Big Smoky Valley, Walker River Valley, near Mono Lake, and elsewhere in Nevada and eastern California. In Utah and in Colorado (especially the San Luis Valley) there are extensive tracts of practically waste land where the varieties *consimilis* and *pinifolius* are abundant. Finally, the Sacramento and San Joaquin valleys of California include large acreages of practically unused alkali lands where, unless the summer heat is too great, *Chrysothamnus* could probably be grown.

Chrysothamnus is thus seen to be a hardy plant capable of growing under a considerable range of climatic and soil conditions. It is apparently best suited to the alkaline plains of the Great Basin, especially if the soil is somewhat sandy. This fact, together with certain other practical considerations, would indicate that if the plants are brought under cultivation the first plantations should be located in these interior districts, some of the most promising of which are those indicated above. Zonal position should be taken into account since it seems unlikely that the best sorts of Rabbit-brush can be grown to advantage outside of the Upper Sonoran Life Zone.

XV. SUMMARY

(1) It was the object of this investigation to discover a supply of rubber in native North American shrubs which might be used in time of war, thus rendering the nation to some extent independent of overseas importations of this substance. The studies were extended to include a preliminary inquiry into the possibility of bringing the plants under cultivation. *Chrysothamnus* or Rabbit-brush, was the genus of shrubs especially studied.

(2) The work was fostered by the Committee on Scientific Research of the State Council of Defense for California and by the University of California. It was furthered through the aid of a considerable number of correspondents.

(3) Chrysil is the name adopted for the particular kind of rubber found in *Chrysothamnus nauseosus*. It is a rubber of high grade and vulcanizes without difficulty.

(4) Rubber was found in two closely related genera of shrubs, namely, *Chrysothamnus* and *Haplopappus*. Only the former yields

Chrysil. The most important species of *Chrysothamnus* is *C. nauseosus,* under which are recognized twenty-two varieties. Twelve of these varieties have been examined and rubber found in all of them although individual plants may be devoid of rubber.

(5) *Chrysothamnus nauseosus* is a large shrub, the average weight being from four to six pounds. It grows readily from seed and reaches maturity in from six to eight years.

(6) The species is widely distributed in western North America, often inhabiting alkaline flats.

(7) The largest stands of Chrysil-bearing shrub are in Colorado, Nevada, and Utah. The plants with the highest rubber content are from Nevada and California. The total amount of rubber present in wild shrub is estimated at over 300,000,000 pounds.

(8) The rubber occurs in the individual cells, and is not a latex-rubber. Its place of occurrence in the plant has been rather definitely located. Methods have been developed for its detection by microscopical examination as well as by chemical analysis. Various experiments indicate that the chemical methods adopted are reasonably accurate; that great care must be exercised in the preparation of samples for analysis; and that samples do not deteriorate when stored for periods of several months.

(9) The results of one hundred and eighty chemical analyses and eighty microscopical examinations are tabulated. These indicate an average of 2.83 per cent of rubber in the variety *hololeucus,* 2.69 per cent in the variety *pinifolius,* 2.52 per cent in the variety *viridulus,* 1.97 per cent in the variety *consimilis,* and lower percentages in other varieties. The low-percentage varieties are all comparatively uncommon. The highest absolute percentage was found in a plant of *consimilis* collected near Gerlach, Nevada, which analyzed 6.57 per cent of pure rubber. The second-highest was a plant of *viridulus* from Benton, California, which yielded 5.56 per cent.

(10) Chrysil occurs in the plant in greatest amount at about the soil line. In the root it is present in only the upper part. In young twigs and leaves it occurs in only small amounts. The richest tissues are found in the cortex and the medullary rays, the former carrying much more than the latter.

(11) The amount of rubber varies with the botanical variety; the best varieties being those which inhabit alkaline soils.

(12) In harvesting wild shrub the whole plant should be taken, including four inches of root. Bulk may be reduced by removing the twigs. Cultivated plants might be so cut as to leave the base of the stem for regeneration.

(13) Because of the desirability of establishing the rubber-growing industry in the United States on waste lands *Chrysothamnus* and other plants should be further investigated with a view to making their cultivation a financial success.

(14) Its cultural requirements are such that *Chrysothamnus* could be grown on many of the alkaline plains of the West without irrigation; certain varieties endure winter temperature of — 20° F.; others would withstand summer temperatures obtaining anywhere in the western states except possibly in the hottest valleys.

PLATE 18

Fig. 1. Photomicrograph of a portion of a cross-section of a twig of the current year—*viridulus*. Stained films in a few cells of the pith, absence of rubber in rays and in cortical parenchyma, accumulation of rubber in the bud intrusion. The chlorenchyma is heavily stained.

Fig. 2. Photograph of a portion of a cross-section of a five-year-old stem—*viridulus*.

a. The outer limits of the rubber-bearing cortex.

b. The tangential zone of maximum, cortical, rubber deposition.

Fig. 3. Photograph of a portion of a three-year-old shoot—*viridulus*. No rubber in the pith.

c. The outer limits of the rubbear-bearing cortex.

Figs. 4 and 5. Photomicrographs showing nature of occurrence of rubber in the cell—*gnaphalodes*.

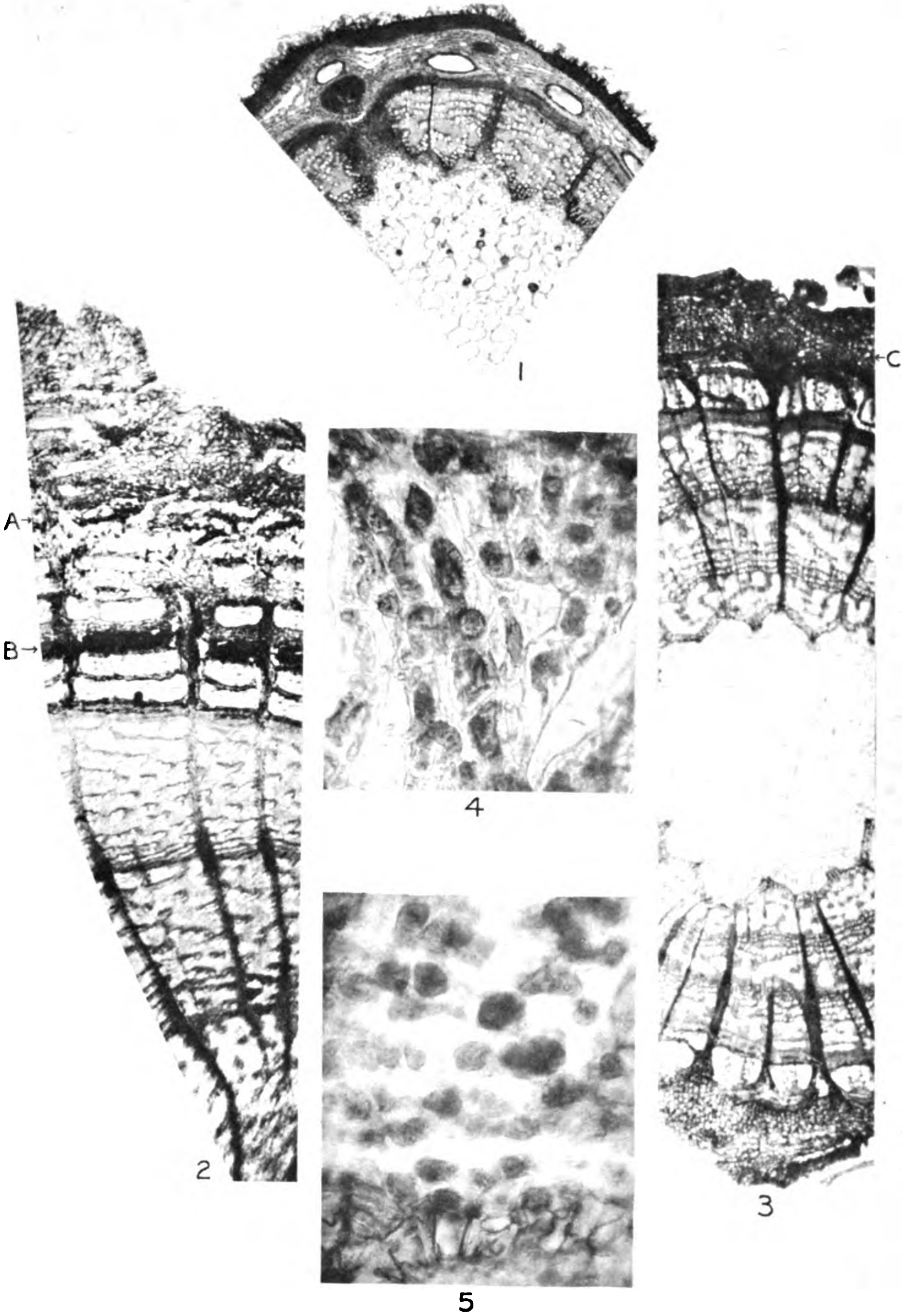
1
A→
B→
2
4
5
←C
3

PLATE 19

Fig. 1. Photomicrograph of a portion of a cross-section of a six-year-old stem—*speciosus*—showing the accumulation of rubber in the rays and their wide cortical extensions.

Fig. 2. Photograph of a portion of a particularly thin cross-section of a nine-year-old stem—*viridulus*.

a. The outer limits of the significant rubber-bearing cortex.

1

2

PLATE 20

Chrysothamnus nauseosus var. *viridulus*. Plant H–3. To illustrate method for increasing weight of rubber-bearing parts.

Fig. 1. The wild plant as it appeared February 16, 1918. Height 5½ feet, spread 5 feet.

Fig. 2. The same plant after pruning, February 16, 1918. Greatest height 3½ feet. The cut branches are 276 in number, one to three years old, and average one-half inch thick.

Fig. 3. The same plant September 16, 1918. Height 4 feet 3 inches, spread 4 feet 6 inches. The number of branches has increased to 640. This increase is somewhat greater than in other plants subjected to the same treatment.

The black stake in figs. 1 and 2 is 40 cm. high. The short stake in all three figures is 4 inches high.

Fig. 1

Fig. 2

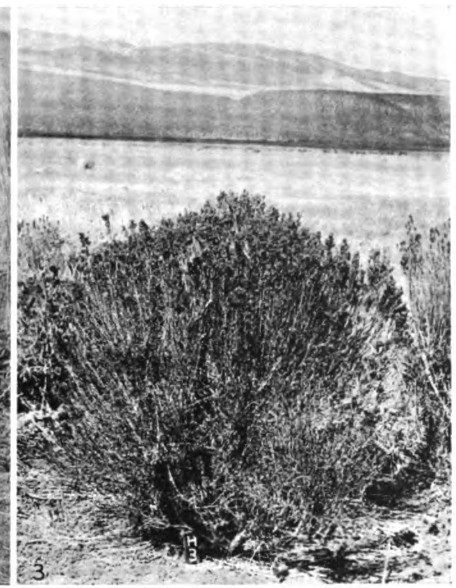

Fig. 3

UNIVERSITY OF CALIFORNIA PUBLICATIONS
IN
BOTANY

Vol. 7, No. 8, pp. 265-278, 2 figures in text November 7, 1919

III. THE OCCURRENCE OF RUBBER IN CERTAIN WEST AMERICAN SHRUBS

BY

HARVEY MONROE HALL and THOMAS HARPER GOODSPEED

CONTENTS

I. *CHRYSOTHAMNUS* (EXCLUSIVE OF *C. NAUSEOSUS*) AND *HAPLOPAPPUS*

In a foregoing report attention has been paid almost exclusively to rubber as it occurs in the numerous varieties of *Chrysothamnus nauseosus*. In the course of the investigation we have also examined as many of the botanically related species and genera as were readily obtainable as well as some species of shrubs not closely related to *Chrysothamnus*. The total number of species of woody plants examined is seventy-nine. As a result of these examinations rubber is now known to occur in four other species of *Chrysothamnus* and in ten species of *Haplopappus*. In no case, however, were we able to detect rubber in any plant other than those showing a close botanical affinity to *Chrysothamnus*. Those in which rubber was found are indicated below. In the tables the percentage of pure rubber is indicated by the benzene extract. All percentages are based upon dry shrub except where "x" indicates that no moisture determination was made.

Chrysothamnus turbinatus (M. E. Jones) Rydb.

The general habit and appearance of this species is very much like that of certain varieties of *C. nauseosus*. Although it differs from that species in what appear to be important technical characters, such as the elongated, columnar involucre, it is not unlikely that further

study will reduce it to a variety of *nauseosus*. The plants are two to four feet high, round-topped, and very twiggy. They grow on sandy mounds of strongly alkaline clay flats. The species has been found only in Utah, and even there it is quite rare. A single sample (410) from the alkaline flats just east of Lund analyzed 4.88 per cent of rubber. Since the species is so close to *nauseosus* botanically it is probable that its rubber is also similar and should be referred to as Chrysil.

Fig. 1. *Chrysothamnus teretifolius* growing among the rocks at Benton Hot Springs, California. Plants average 1½ feet high.

Chrysothamnus teretifolius (Dur. and Hilg.) Hall.

This is a low, broadly branched, woody plant, sometimes as much as six feet high and fully as broad, but usually much smaller (cf. fig. 1). Average plants will weigh one to three pounds. The largest we have seen had several trunks each eight inches thick and the whole plant had an estimated weight of twenty pounds. Unlike the genuine species of *Chrysothamnus* this one has a very resinous herbage and because of this it is placed in the genus *Ericameria* by some botanists. It grows on gravelly or stony hillsides, often in rocky cañon bottoms,

and although it never forms pure stands of any great extent yet a considerable supply could be assembled from some of the desert ranges. The distribution of *teretifolius* is from the easterly slope of the Sierra Nevada and Tehachapi mountains to central Nevada and possibly Arizona. The largest stands we have seen are in the cañons on both slopes of the White and Inyo ranges in eastern California; there is also a considerable quantity on the mountains to the west of Antelope Valley, California.

TABLE 1—CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
45	Near Rosamond, Calif.	Oct. 26, 1917	5.46	2.80
436	Lida, Nev.	Sept. 10, 1918	2.85	1.67
440	West of Deep Spring Valley, Calif.	Sept. 12, 1918	2.22	2.48
575	Near Benton, Calif.	Dec. 23, 1918	4.61	4.51^{x}
592	Near Victorville, Calif.	Dec. 25, 1918	4.93	2.04^{x}

MICROSCOPICAL EXAMINATIONS

	Place of Collection	Date of Collection	Estimated Amount
61	Near Bishop, Calif.	Nov. 1, 1917	Fair
67	Benton Hills, Calif.	Nov. 4, 1917	Fair
76	Near Candelaria, Nev.	Oct. 8, 1917	Poor
82	Near Benton, Calif.	Nov. 11, 1917	Good
83	Silver Cañon, Inyo Mts., Calif.	Nov. 12, 1917	Fair
85	Near Owenyo, Inyo Co., Calif.	Nov. 14, 1917	Fair

Chrysothamnus paniculatus (Gray) Hall.

The plants of this species are on the average taller and less spreading than *C. teretifolius* but they have a similarly glandular-dotted foliage and the two are very close botanically. It grows on the southerly part of the Mojave Desert and from Whitewater, on the west side of the Colorado Desert, east to Arizona but it is nowhere abundant. Six samples have been examined, with the following results.

TABLE 2—CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
579	North of Barstow, Calif.	Dec. 24, 1918	2.73	1.20^{x}
580	North of Barstow, Calif.	Dec. 24, 1918	4.10	3.24^{x}

MICROSCOPICAL EXAMINATIONS

	Place of Collection	Date of Collection	Estimated Amount
96	Cabazon, Calif.	Jan. 22, 1918	Fair
98	West of Whitewater, Calif.	Jan. 22, 1918	Fair
99	North side of San Jacinto Mountain, Calif.	Jan. 22, 1918	Fair
581	North of Barstow, Calif.	Dec. 24, 1918	Poor

Chrysothamnus linifolius Greene.

This is perhaps only a variety of *C. viscidiflorus* but it differs from all other forms of that exceedingly variable species in the taller and more robust habit (the woody stems are sometimes eight feet high), in the broadly linear leaves, and in the greenish thickened tips of the involucral bracts. Its ecologic habitat is also different, since it grows only in alkaline soil, whereas the forms of *viscidiflorus* are confined to well drained, non-alkaline slopes and benches. This may account for the occurrence of rubber in *linifolius,* and its absence in *viscidiflorus* as well as in two other very closely related upland species, namely, *humilis* and *puberulus.* This is in accord with what has been found in *C. nauseosus,* in which species, as noted elsewhere,[1] the varieties carrying the most rubber are all inhabitants of alkaline soils.

Only two samples of *linifolius* have been examined. One (400) from an alkaline flat near Grand Junction, Colorado, yielded on analysis 1 per cent of rubber. The other (515), which was gathered at Green River, Utah, was not analyzed. A microscopic examination failed to detect any rubber in it.

Haplopappus nanus D. C. Eaton

The stems of this species are very low, one foot or less in height, much gnarled and branched and with numerous short leafy twigs. They have a thick, corky bark and a considerable portion of the wood is dead in many of the plants. The foliage is deep green and quite resinous. Average plants will weigh about one pound but it is usually impossible to obtain the whole plant since the roots are tightly held by the rocks in which they grow. The species inhabits rocky ledges and outcroppings and may be expected on almost any of the mountain ranges of the Great Basin area. It is known to grow in such situations from Mono County, California, to southwestern Utah and north to Washington. Wherever we have found it during the course of these investigations it was growing in only limited quantities and there are probably no considerable stands of it anywhere. (See fig. 2.)

The percentage of rubber in *Haplopappus nanus* is the highest known for any native American shrub except Guayule, our analyses, four in number, indicating that it runs from 6 to 10 per cent of the dry weight of the entire plant. The quality of the product would probably be inferior to that of the *viridulus* form of *Chrysothamnus* because of the large amount of resins present. A sample was worked out mechan-

[1]See p. 245.

ically, separated in water, and found to be rather soft and dark colored. It was not subjected to detailed examination. The recovery of any considerable amount of rubber from the wild shrub is practically impossible because of the very limited known supply. It is conceivable that under cultivation it might grow to good size and at the same time retain its fairly high rubber content and that both the size of plant and percentage of rubber could then be increased by selection or breeding, but the outlook for this is not promising.

Six samples have been examined and five of them are reported on below. A considerable variation in the rubber content is to be expected since much depends upon the amount of dead wood present in the sample. Usually this is considerable since the plants are very old and grow under extremely adverse conditions. The analyses are for the whole plant (after the obviously dead branches had been removed) except that only the upper portion of the root is included. One other sample (438, from near Deep Spring Valley, California) was analyzed with the result that the amount of the benzene extract was negligible. This is omitted from the table since the plant was not in a condition to permit of a positive identification. It may belong to some other species or even to another genus.

Fig. 2. *Haplopappus nanus*, plant no. 206, Benton Hills, California. Total height as illustrated, 1½ feet.

TABLE 3—CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
71	Near Benton, Calif.	Nov. 4, 1917	7.85*	9.46*
206	Near Benton, Calif.	Feb. 19, 1918	9.57	6.72
256	Shoshone Falls, Idaho	June 23, 1918	5.86	4.61
416	Caliente, Nev.	Sept. 6, 1918	4.49	8.42

MICROSCOPICAL EXAMINATION

	Collection	Date of Collection	Estimated Amount
75	Near Candelaria, Nev.	Oct. 8, 1917	Good

*Based on air-dried sample analyzed by Professor P. L. Hibbard; if perfectly dry the benzene extract would probably be between 9.6 and 10 per cent.

Haplopappus cervinus Wats.

This is a low shrub, scarcely a foot high, with resinous-punctate leaves. It grows in the foothill cañons of western Utah and is especially common along the east side of Salt Lake Valley, where, however, it does not grow in continuous belts. The quality of the rubber is probably similar to that of *Haplopappus nanus,* of which *cervinus* is perhaps only a variety. The above-ground portions of four samples submitted by Professor Marcus E. Jones have been analyzed with the following result.

TABLE 4—CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
510	Near Salt Lake, Utah	Oct. 7, 1918	4.63	4.03
535	Parleys Cañon, Utah	Dec. 22, 1918	5.58	2.28
536a	Parleys Cañon, Utah	Dec. 22, 1918	5.68	2.21
537	Parleys Cañon, Utah	Dec. 22, 1918	5.54	2.90[x]

Haplopappus ericoides (Less.) H. & A.

This heather-like shrub grows one to five feet high. The main stems are one to three inches thick at base, either erect or decumbent, and emit numerous erect branchlets densely clothed with short narrow leaves, the whole plant thus resembling heather. The herbage is green and resinous. The plants grow in sandy soil and are most abundant as well as of greatest size in the sand dunes along the seashore, where they sometimes form extensive colonies. The species extends geographically along the California coast from southern Los Angeles County to San Francisco. The distribution of rubber in this plant is peculiar, if a sample gathered in the sand dunes near Moss Beach, south of San Francisco, is characteristic of the species. Only traces of rubber were found in the stems of this plant but in the root, which was analyzed in sections, the percentage gradually increased until at a depth of two feet it was 3.92.

TABLE 5—CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.	Remarks
93	Duarte, Calif.	Jan. 20, 1918	5.49	0.49	Base of stem
149	Moss Beach, Calif.	May 23, 1918	9.17	3.92	End of root; 50 cm. below soil line
	Moss Beach, Calif.	May 23, 1918	7.47	3.11	Next 20 cm. up root
	Moss Beach, Calif.	May 23, 1918	5.16	1.67	Next 20 cm. up root
	Moss Beach, Calif.	May 23, 1918	5.49	0.58	10 cm. below soil line
157	San Francisco, Calif.	July 27, 1918	6.67	2.10	Root; piece 50 cm. below soil line
	San Francisco, Calif.	July 27, 1918	5.14	0.75	Root; piece 10 cm. below soil line
	San Francisco, Calif.	July 27, 1918	9.10	0.19	Base of stem
743	Duarte, Calif.	Jan. 1, 1919	3.72	0.13	Base of stem
	Duarte, Calif.	Jan. 1, 1919	7.51	0.25	Twigs
	Duarte, Calif.	Jan. 1, 1919	3.95	0.90	Entire root
744	Duarte, Calif.	Jan. 1, 1919	3.11	0.27	Stem
745	Duarte, Calif.	Jan. 1, 1919	4.07	0.38	Stem
	Duarte, Calif.	Jan. 1, 1919	4.81	1.97	Root
	Duarte, Calif.	Jan. 1, 1919	3.32	0.19	Tops; 3 years old and younger

MICROSCOPICAL EXAMINATIONS

	Place of Collection	Date of Collection	Estimated Amount
95	Claremont, Calif.	Jan. 20, 1918	Poor
137	San Francisco, Calif.	Mar. 28, 1918	Poor
138	San Francisco, Calif.	Mar. 28, 1918	Poor
156	San Francisco, Calif.	July 27, 1918	Poor

Haplopappus Palmeri Gray.

In habit and general appearance this species is much like *H. ericoides* except that the plants are usually smaller. It belongs to southern California and is especially common on the plains and lower foothills of the coastal slopes. It is absent from the sand dunes along the coast. One sample (725) from Riverside was found to contain 0.91 per cent of rubber. Another (721), also from Riverside, and one (201) from Colton were examined microscopically but no rubber could be detected in either of them.

Haplopappus pinifolius Gray.

This southern California species is much like *H. ericoides*. One collection (129) made near San Bernardino, was examined microscopically, and found to contain but a small amount of rubber. A second sample was taken in San Fernando Valley and found to contain 1.61 per cent in the basal portion of the stem.

Haplopappus monactis Gray.

This is a good sized shrub, commonly two or three feet high, sometimes six feet high and with a trunk diameter of four inches; in one case there were three principal branches, each one to three inches thick. The weight is estimated at five pounds for average plants; thirty pounds for exceptionally large ones. The species is most abundant around the westerly extensions of the Mojave Desert but it grows at many places along the desert borders and east into southern Nevada; also to a very limited extent on the coastal slope of southern California. One large shrub (90) was collected near Elizabeth Lake and examined microscopically. It appeared to contain a fair amount of rubber. A much smaller one (713) from near Hesperia was analyzed and found to contain only 0.38 per cent of rubber.

Haplopappus laricifolius Gray.

Very close botanically to *H. monactis*, this species is also like it in habit, general appearance, and rubber content. It grows in southern Arizona, but apparently it is not abundant. Five samples have been examined with the result indicated below.

Table 6—Chemical Analyses

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
760	Near Tucson, Ariz.	Feb. 18, 1919	3.44	5.16
783*	Santa Catalina Mts., Ariz.	Mar. 16, 1919	5.44	2.32
783†	Santa Catalina Mts., Ariz.	Mar. 16, 1919	3.62	3.37
786*	Tucson Mts., Ariz.	Mar. 23, 1919	3.94	2.01
786†	Tucson Mts., Ariz.	Mar. 23, 1919	3.33	2.87

* Stem.

† Root.

Microscopical Examination

	Place of Collection	Date of Collection	Estimated Amount
158	Near Tucson, Ariz.	July 27, 1918	Fair

Haplopappus arborescens (Gray)[2]

Although this is one of the largest species of the genus it is not really arborescent, as its specific name would seem to indicate. However, the woody stems are often several inches thick at the base and the shrubs are commonly three to five feet high. The species is common in the Coast Ranges of middle California and occurs also in the foothills of the Sierra Nevada. Two specimens (151, 152), both from one station on Mt. Tamalpais, showed only traces of rubber on microscopical examination.

Haplopappus brachylepis (Gray)[3]

The geographic distribution of *H. brachylepis* is restricted to a small area in southwestern San Diego County, California, and to northern Lower California. The species is a large shrub, commonly three to six feet high, with brittle stems. It grows in the arid chaparral belt, usually on stony hillsides. Four samples taken in San Diego County, near the borders of Lower California, were examined with results as indicated below.

TABLE 7—CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
728	El Campo, Calif.	Dec. 29, 1918	13.18	0.81
730	El Campo, Calif.	Dec. 29, 1918	10.69	0.16

MICROSCOPICAL EXAMINATIONS

	Place of Collection	Date of Collection	Estimated Amount
727	El Campo, Calif.	Dec. 27, 1918	Nothing
729	El Campo, Calif.	Dec. 29, 1918	Traces

Haplopappus linearifolius DC.

This is an erect shrub two to five feet high, with stems commonly one to four inches thick, and resinous herbage. It grows from Lake County, in the Coast ranges, south into Lower California and east to southern Utah and Arizona. It is perhaps most plentiful around the borders of Antelope Valley, California. There are two forms. Typical *linearifolius* grows in the Coast ranges. The other form, distinguished by its shorter leaves and smaller heads, replaces it in the desert country and is known as var. *interior* (Coville) M. E. Jones.

[2] *Haplopappus arborescens* (Gray) H. M. Hall, comb. nov. *Linosyris arborescens* Gray, Bot. Mex. Bound. (1859), p. 79.

[3] *Haplopappus brachylepis* (Gray) H. M. Hall, comb. nov. *Bigelovia brachylepis* Gray, Bot. Calif., vol. 1 (1876), p. 614.

In the following tabulation of examinations, only nos. 492 and 493 represent typical *linearifolius;* the remainder are of the *interior* variety.

TABLE 8—CHEMICAL ANALYSES

	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.
492	South of Antioch, Calif.	Oct. 12, 1918	2.47	0.30
493	South of Antioch, Calif.	Oct. 12, 1918	1.53	0.03
701	Mojave Desert, Calif.	Dec. 25, 1918	3.15	1.21
702	Mojave Desert, Calif.	Dec. 25, 1918	3.32	1.32
703	Mojave Desert, Calif.	Dec. 25, 1918	3.13	1.19
714	Near Hesperia, Calif.	Dec. 26, 1918	2.78	0.45

MICROSCOPICAL EXAMINATION

	Place of Collection	Date of Collection	Estimated Amount
89	Del Sur, Antelope Valley, Calif.	Jan. 19, 1918	Poor

II. REGIONAL DISTRIBUTION OF RUBBER IN *HAPLOPAPPUS*

We have shown that Chrysil is peculiar to the part of the plant above ground, analyses of root and stem indicating that below a point approximately 10 cm. beneath the soil line rubber occurs in negligible quantities even if the parts above are relatively rich in this substance. In the case of at least two species of *Haplopappus* a different distribution obtains as is indicated by the results given in the following table.

TABLE 9—REGIONAL DISTRIBUTION OF RUBBER IN *Haplopappus*

Collection Number	Species	Place of Collection	Date of Collection	Acetone Extract Per cent.	Benzene Extract Per cent.	Remarks
149	Haplopappus ericoides	Moss Beach, Calif.	May 23, 1913	9.17	3.92	End of root 50 cm. below soil line
		Moss Beach, Calif.	May 23, 1918	7.47	3.11	Next 20 cm. up root
		Moss Beach, Calif.	May 23, 1918	5.16	1.67	Next 20 cm. up root.
		Moss Beach, Calif.	May 23, 1918	5.49	0.58	10 cm. below soil line
157	Haplopappus ericoides	San Francisco, Calif.	July 27, 1918	6.67	2.10	Root; piece 50 cm. below soil line
		San Francisco, Calif.	July 27, 1918	5.14	0.75	Root; piece 10 cm. below soil line
		San Francisco, Calif.	July 27, 1918	9.10	0.19	Base of stem
206	Haplopappus nanus	Near Benton, Calif.	Feb. 19, 1918	9.57	6.72	Stem
		Near Benton, Calif.	Feb. 19, 1918	5.96	5.29	Root
256	Haplopappus nanus	Shoshone Falls, Idaho	June 23, 1918	22.58	0.64	Leaves
		Shoshone Falls, Idaho	June 23, 1918	8.94	2.69	Twigs
		Shoshone Falls, Idaho	June 23, 1918	5.86	4.61	Stem
743	Haplopappus ericoides	Duarte, Calif.	Jan. 1, 1919	3.72	0.13	Base of stem
		Duarte, Calif.	Jan. 1, 1919	7.51	0.25	Twigs
		Duarte, Calif.	Jan. 1, 1919	3.95	0.90	Entire root
745	Haplopappus ericoides	Duarte, Calif.	Jan. 1, 1919	4.07	0.38	Stem
		Duarte, Calif.	Jan. 1, 1919	4.81	1.97	Root
		Duarte, Calif.	Jan. 1, 1919	3.32	0.19	Tops; 3 years old and younger

It seems clear from the results included in the above table that the root areas of the two species of *Haplopappus* examined contain appreciable quantities of rubber. In the case of *H. ericoides* the parts above the soil line are strikingly deficient in rubber as compared with the roots. Indeed, in the extremities of the root the percentage is often highest and decreases as one passes upward towards the soil line. The regional distribution in *ericoides* is, thus, the reverse of that found in the various varieties of *Chrysothamnus.*

In *H. nanus,* on the other hand, stem and root appear to bear equal quantities of rubber. The evidence here is obviously fragmentary but the above statement holds rather strictly for 206, and in the case of 256 the stem probably bears a maximum quantity for this plant and it might be assumed that the root, if analyzed, would show an approximately equal amount.

It appears, then, that three types of regional distribution of contained rubber are shown by the plants which we have examined in the course of the entire investigation. In the first place, the maximum quantity is borne by the stem. This is peculiar to the distribution of Chrysil. In the second place, root and stem bear equal amounts. This condition obtains in *Haplopappus nanus.* Finally, we have the case in which the root carries almost the entire amount of rubber borne by the plant, *H. ericoides.* This seems a rather remarkable situation and one which would repay further investigation. In particular it would be important to examine in detail the distribution of rubber in the other species of *Haplopappus* not investigated in this particular connection by us.

III. SPECIES IN WHICH NO RUBBER WAS FOUND

In the course of the investigation reported on in the foregoing pages a miscellaneous collection of plants was made as opportunity offered and these have been examined histologically for rubber content with the result that rubber was located in certain cases but only in species of *Chrysothamnus* or of related genera. This occurrence has been noted in the preceding list but it now remains to enumerate those species in which no rubber could be detected with certainty. This list is given as it may be of some service in case a more extensive survey is undertaken. As in the preceding report, the numbers refer to field notes and have been assigned merely for convenience of reference. The locality mentioned in each case is the place of collection.

I. COMPOSITAE

700. *Acamptopappus sphaerocephalus.* Near Hesperia, California.
491. *Artemisia californica.* Antioch, California.
19. *Artemisia filifolia.* Denver, Colorado.
460. *Artemisia Rothrockii.* Tioga Pass, California.
8. *Artemisia tridentata.* Truckee, California.
589. *Baccharis glutinosa.* Barstow, California.
747. *Baccharis pilularis.* Near Ventura, California.
97. *Baccharis sergiloides.* Near Banning, California.
751. *Bebbia juncea.* Palm Springs, California.
595. *Brickellia atractyloides.* Near Victorville, California.
596. *Brickellia desertorum.* Near Victorville, California.
513*a*. *Brickellia microphylla.* Near Salt Lake, Utah.
409. *Chrysothamnus Greenei.* Lund, Utah.
285. *Chrysothamnus Howardi.* Near Walsenburg; also no. 287, Cañon City, and no. 292, Villa Grove; all in Colorado.
458. *Chrysothamnus nevadensis.* Mono Mills, California.
18. *Chrysothamnus Parryi.* Teller Lake, Colorado.
9. *Chrysothamnus humilis.* Truckee Valley, California.
14. *Chrysothamnus puberulus.* Pyramid Lake, Nevada; also 23, Tonopah, Nevada; also 28, 29, Reno, Nevada; and 259, southeastern Idaho.
7. *Chrysothamnus viscidiflorus* var. *tortifolius.* Truckee Valley, California; also 30, Reno, Nevada.
746. *Corethrogyne filaginifolia.* Near Ventura, California.
763. *Dysodia porophylloides.* Palm Springs, California.
736. *Encelia californica.* Near San Diego, California.
598. *Encelia farinosa.* Near Victorville, California; also 722, Riverside, California.
68. *Ericameria cuneata spatulata.* Benton, Mono County, California; also near Victorville, California.
86. *Franseria dumosa.* Owenyo, California; also 587, Barstow, California.
594. *Gnaphalium bicolor.* Near Victorville, California.
490. *Gutierrezia californica.* Antioch, California.
46. *Guiterrezia lucida.* Rosamond, California; also 586, Barstow, California.
558. *Gutierrezia Sarothrae.* Near Reno, Nevada.
38. *Haplopappus Bloomeri.* Truckee, California.
273. *Haplopappus Fremonti.* Laramie, Wyoming.
735. *Hazardia squarrosa.* El Campo, San Diego County, California.
764. *Hofmeisteria pluriseta.* Palm Springs, California.
73. *Hymenoclea salsola.* Mina, Nevada; also 585, Barstow, California.
761. *Isocoma coronopifolia.* Near Tucson, Arizona.
160. *Isocoma Hartwegi.* Near Tucson, Arizona; also 762, from Tucson.
427. *Isocoma veneta acradenia.* Las Vegas, Nevada; also 599, Victorville, California.
94. *Lepidospartum squamatum.* Duarte, California.
242. *Picradenia Lemmoni.* Near Weed, California.
560. *Tetradymia canescens.* Near Reno, Nevada; also 433, Goldfield, Nevada.

II. MISCELLANEOUS FAMILIES

741. *Astragalus leucopsis* (*Leguminosae*). Near San Diego, California.
425. *Atriplex canescens* (*Chenopodiaceae*). Las Vegas, Nevada.
24. *Atriplex confertifolia* (*Chenopodiaceae*). Tonopah, Nevada; also 582. Barstow, California.
740. *Cneoridium dumosum* (*Rutaceae*). Near San Diego, California.
31. *Ephedra nevadensis* (*Gnetaceae*). Reno, Nevada.
707. *Eriodictyon californicum* (*Hydrophyllaceae*). Mojave Desert, California.
432. *Eriogonum fasciculatum* var. (*Polygonaceae*). Goldfield, Nevada.
494. *Eriogonum nudum* (*Polygonaceae*). Mt. Diablo, California.
74. *Eurotia lanata* (*Chenopodiaceae*). Mina, Nevada.
734. *Frasera Parryi* (*Gentianaceae*). El Campo, San Diego County, California.
426. *Glycyrrhiza lepidota* (*Leguminosae*). Las Vegas, Nevada.
597. *Isomeris arborea* (*Capparidaceae*). Near Victorville, California.
584. *Larrea divaricata* (*Zygophyllaceae*). Near Barstow, California.
429. *Lepidium Fremonti* (*Cruciferae*). Indian Spring, Nevada.
583. *Lycium Cooperi* (*Solanaceae*). Near Barstow, California.
422. *Olneya tesota* (*Leguminosae*). Las Vegas, Nevada.
423. *Prosopis juliflora* (*Leguminosae*). Las Vegas, Nevada.
424. *Prosopis pubescens* (*Leguminosae*). Las Vegas, Nevada.
742. *Rhamnus crocea* (*Rhamnaceae*). Near San Diego, California.
739. *Rhus integrifolia* (*Anacardiaceae*). Near San Diego, California.
732. *Rhus ovata* (*Rhamnaceae*). El Campo, San Diego County, California.
420. *Rhus trilobata* (*Anacardiaceae*). Las Vegas, Nevada; also 733, El Campo, California.
15. *Sarcobatus vermiculatus* (*Chenopodiaceaè*). Near Pyramid Lake, Nevada; also 33, same locality.
738. *Simmondsia californica* (*Buxaceae*). Near San Diego, California.

Vol. 5. 1912-.

1. Studies in *Nicotiana*, I, by William Albert Setchell. Pp. 1-86. December, 1912 .... 1.25
2. Quantitative Studies of Inheritance in *Nicotiana* Hybrids, I, by Thomas Harper Goodspeed. Pp. 87-168. December, 1912 .... 1.00
3. Quantitative Studies of Inheritance in *Nicotiana* Hybrids, II, by Thomas Harper Goodspeed. Pp. 169-188. January, 1913 .... .20
4. On the Partial Sterility of *Nicotiana* Hybrids made with *N. sylvestris* as a Parent, by Thomas Harper Goodspeed. Pp. 189-198. March, 1913 .... .10
5. Notes on the Germination of Tobacco Seed, I, by Thomas Harper Goodspeed. Pp. 199-222. May, 1913 .... .25
6. Quantitative Studies of Inheritance in *Nicotiana* Hybrids, III, by Thomas Harper Goodspeed. Pp. 223-231. April, 1915 .... .10
7. Notes on the Germination of Tobacco Seed, II, by Thomas Harper Goodspeed. Pp. 233-248. June, 1915 .... .15
8. Parthenogenesis, Parthenocarpy and Phenospermy in *Nicotiana*, by Thomas Harper Goodspeed. Pp. 249-272, plate 35. July, 1915 .... .25
9. On the Partial Sterility of *Nicotiana* Hybrids made with *N. sylvestris* as a Parent, II, by T. H. Goodspeed and A. H. Ayres. Pp. 273-292, plate 36. October, 1916 .... .20
10. On the Partial Sterility of *Nicotiana* Hybrids made with *N. sylvestris* as a Parent, III, An Account of the Mode of Floral Abscission in the F_1 Species Hybrids, by T. H. Goodspeed and J. N. Kendall. Pp. 293-299. November, 1916 .... .05
11. The Nature of the F_1 Species Hybrids between *Nicotiana sylvestris* and Varieties of *Nicotiana Tabacum*, with Special Reference to the Conception of Reaction System Contrasts in Heredity, by T. H. Goodspeed and R. E. Clausen. Pp. 301-346, plates 37-48. January, 1917 .... .45
12. Abscission of Flowers and Fruits in the Solanaceae, with Special Reference to *Nicotiana*, by John N. Kendall. Pp. 347-428, 10 text figures, plates 49-53. March, 1918 .... .85
13. Controlled Pollination in *Nicotiana*, by Thomas Harper Goodspeed and Pirie Davidson. Pp. 429-434. August, 1918 .... .10
14. An Apparatus for Flower Measurement, by T. H. Goodspeed and R. E. Clausen. Pp. 435-437, plate 54, 1 figure in text. September 25, 1918 .05
15. Note on the Effects of Illuminating Gas and its Constituents in Causing Abscission of Flowers in *Nicotiana* and *Citrus*, by T. H. Goodspeed, J. M. McGee and R. W. Hodgson. Pp. 439-450. December, 1918 .... .15
16. Notes on the Germination of Tobacco Seed, III. Note on the Relation of Light and Darkness to Germination, by T. Harper Goodspeed. Pp. 451-455. April, 1919 .... .05

Vol. 6. 1914-.

1. Parasitic Florideae, by William Albert Setchell. Pp. 1-34, plates 1-6. April, 1914 .... .35
2. *Phytomorula regularis*, a Symmetrical Protophyte Related to *Coelastrum*, by Charles Atwood Kofoid. Pp. 35-40, plate 7. April, 1914 .... .05
3. Variation in *Oenothera ovata*, by Katherine Layne Brandegee. Pp. 41-50, plates 8-9. June, 1914 .... .10
4. Plantae Mexicanae Purpusianae, VI, by Townshend Stith Brandegee. Pp. 51-77. July, 1914 .... .25
5. The *Scinaia* Assemblage, by William Albert Setchell. Pp. 79-152, plates 10-12. October, 1914 .... .75
6. Notes on Pacific Coast Algae, I, *Pylaiella Postelsiae*, n. sp., a New Type in the Genus *Pylaiella*, by Carl Skottsberg. Pp. 153-164, plates 17-19. May, 1915 .... .15
7. New and Noteworthy Californian Plants, II, by Harvey Monroe Hall. Pp. 165-176, plate 20. October, 1915 .... .15
8. Plantae Mexicanae Purpusianae, VII, by Townshend Stith Brandegee. Pp. 177-197. October, 1915 .... .25